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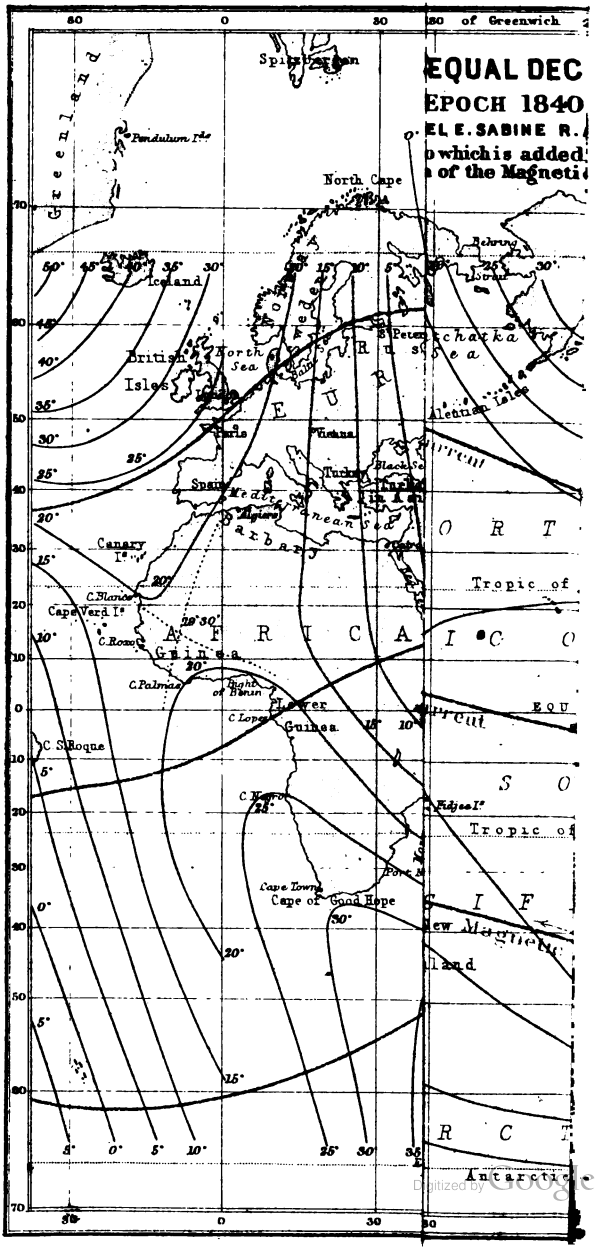

AN ENQUIRY

INTO THE

NATURE AND RESULTS

OF

ELECTRICITY AND MAGNETISM.

BY

AMYCLANUS.

LONDON:
R. WASHBOURNE, 18 PATERNOSTER ROW.
1876.

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PREFACE.

THE following lectures on the nature and effects of electricity were originally put together for the benefit of a young men's reading club. This circumstance may serve to explain the popular form in which they have been cast. They are now presented to the public, having been considerably enlarged, and almost entirely rewritten. The writer lays no claim to the merit of having made any original researches into the department of science which is here treated. What he has aimed at doing is this, to collect a number of facts well attested, and bearing upon one another, and to proceed then, with the aid of that which may be looked upon as certain, to clear up as far as possible that which yet remains doubtful and obscure. Had he been able to verify for himself the principal facts out of which he has built up his theory concerning the nature of electricity, he would undoubtedly have been more secure against the danger of error in judging of their force and significancy, and would in many ways have been greatly assisted in the execution of his task. Unfortunately he has not had it in his power to do so.

His knowledge of the experimental truths of the science has been drawn principally from two excellent manuals, the one entitled the "Student's Textbook of Electricity," by Dr. Noad; the other, "Electricity," by Dr. Ferguson. He acknowledges himself indebted to them to a greater extent than might appear from the occasional reference which is made to their pages. The map which comes at the beginning, showing the lines of equal declination over the globe, has been taken by permission from Keith Johnston's "Physical Atlas of Natural Phenomena."

The writer is well aware that some of the conclusions he comes to differ widely from the generally received doctrine of the present day, and, however well grounded they may be, he cannot expect their truth to be admitted until they have passed through the ordeal of a severer investigation than they have here been subjected to. He asks for nothing more than that the arguments he has brought forward be candidly considered and impartially weighed.

In the following pages allusion is seldom made to the names of those who have most distinguished themselves by their labours in this branch of science. The reason is, not that the writer undervalues what has been done by others—the fruit of whose labours he seeks to gather up—but because, not having any claim to speak with authority, he has judged it more fitting to confine himself strictly to the subject in hand.

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ELECTRICITY.

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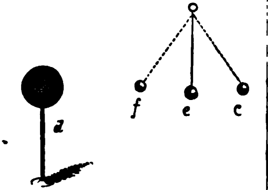


FIG. 1.—*a*, Insulating glass stand. *b*, Insulated c
d, Uninsulated ball. *c*, Pith ball attracted t
charged by contact with electrified ball propel

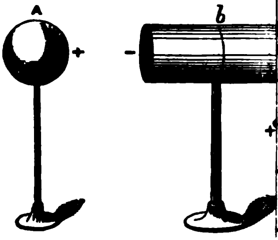


FIG. 2.—A, Brass ball insulated and charged. *b*,
line between positive and negative pole. C
balls positively charged and attracted differe

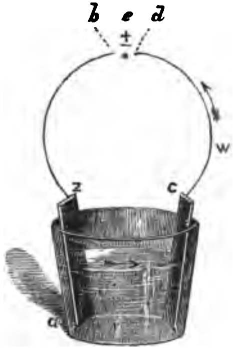


FIG. 3, 3i.—*a*, Vessel of acidulated water. Z, Zinc
conductor. *d*, Wire intersected first between
between *b* and *e*. *f*, Vessel of diluted sulph
attracted to copper plate. · Molecule of oxyg

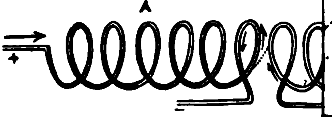
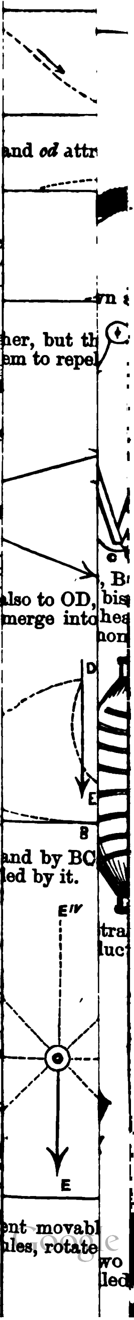


FIG. 4.—A, Left-handed solenoid or helix. B, Rig
poles in dissimilar solenoids will attract one an



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ELECTRICITY.

LECTURE I.

INTRODUCTION—VARIOUS FORMS OF ELECTRICITY.

Diffusion of electricity through nature — No essential difference between its various forms—Its dualistic power.

I AM going to speak to you on the subject of electricity, which is at the same time one of the most widely diffused and one of the most mysterious of physical agents. It pervades every part of the material world. We discover traces of its presence in the animal no less than in the vegetable and mineral kingdoms; and in the effects which it produces it exhibits a power as subtile and as variable as it is penetrating and far-reaching. Perhaps in no other department of physical science do we meet with so many curious and interesting phenomena as in this. It is not, however, my object to marshal together the many singular and striking facts which present themselves to our view in connection with this science, but rather to give you an insight into what, according to my idea, electricity is. I shall therefore, in my treatment of the subject, confine myself to the notice of such facts as I think will help you to arrive at a true and just conception of this most mysterious agent. To attempt to give in a few words any intelligible account of so abstruse and difficult a subject as that which I am about to deal with is no easy task. I shall try, however, to be as brief as possible; whilst bringing before you whatever seems to me to be necessary, or in any way important, in order to enable you to judge correctly concerning the matter under discussion.

At the outset we are met with the question, Are there two distinct kinds of electricity, differing from each other essentially; or is there, properly speaking, only one kind, subject to certain modifications?

Vitreous substances, such as glass, become excited by being rubbed with certain other substances, and in this state they attract light bodies. Resinous substances, such as sealing-wax and gutta-percha, become also excited when rubbed with certain other substances, and in this state they also attract light substances. Bodies which are charged with the same kind of electricity, by having been brought into contact with excited vitreous substances, appear to repel one another. Bodies which are charged with opposite electricities, from having been brought into contact one with an excited vitreous the other with an excited resinous substance, attract one another. Are there here two altogether distinct kinds of electricity, with which these bodies are excited? I think it has been satisfactorily shown that there is no radical difference between them. Vitreous substances can be brought to a state of resinous electricity; resinous substances can be brought to a state of vitreous electricity. Let a glass rod be rubbed with a woollen cloth, the glass rod will first attract a pith ball and afterwards repel it. The woollen cloth being then presented will be found to attract the excited ball. As the glass was vitreously electrified, we conclude that the woollen cloth must be resinously electrified.

Next, let a stick of sealing-wax be rubbed with a woollen cloth, it will first attract a pith ball and afterwards repel it. The woollen cloth being now presented will be found to attract the pith ball. Hence, by a similar reasoning, we infer that the woollen cloth is vitreously electrified.

Again, let a piece of polished glass be rubbed first with a woollen cloth and then with the fur of a cat. Being examined after each excitation by a pith ball, it will be found in the first case vitreous, in the second resinous. A woollen cloth and a piece of glass are thus made to exhibit both kinds of electricity.*

These terms therefore, inasmuch as they seem to imply that when vitreous substances are electrified they are always under the influence of one particular species of electricity, and that when resinous substances are electrified they are always charged with a different species of electricity, are objectionable, being calculated to convey a false idea of the difference which exists between the one form of electricity and the other.

The terms *positive* and *negative* as applied to electricity, are less liable to exception. They do not necessarily imply that these are two electricities having a different origin; they affirm nothing more than a difference of relation between the one and the other. And this is the only difference the existence of which can be said to be proved. Neither of them is ever found alone, the one being the complement and counterpart of the other.

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* Noad's "Student's Textbook of Electricity," p. 3.

We see this to be the case in current electricity. In the galvanic trough, in which the electric current is generated, the one plate is electrified positively, the other negatively. And if the conducting wire, which unites the two plates together, be divided without the parts being so far separated as to break the electric connection, the face of the one terminal will be found to be positive, the face of the other negative; or rather the same particle in the circuit will be at once positive and negative—positive in relation to the parts that lie on the one side of it, negative in relation to the parts that lie on the other.

Let the connecting wire, Fig. 3, be divided between *d* and *e*, the particle *e* on the edge of the intersection will be negative. Let the intersection of the wire be made between *e* and *b*, the same particle *e* will now be positive. If the particle *e* consists of two elements, as in the case of a particle of brass, which is formed of copper and zinc, we might suppose one of the two to be negative, the other positive. But when *e* is a simple, not a compound substance, as *e.g.* a particle of copper, the same particle must be at the same time both positive and negative, in so far as it stands related to both the negative and positive elements in the galvanic cell. In other words, a current of electric action both positive and negative runs simultaneously along the connecting wire in different ways, although, when we speak of the direction of the current upon a conducting wire, we usually take notice of one only of the two currents, viz. the positive one. Similarly we find one and the same substance electro-positive and electro-negative, when we consider it in relation to different substances. Thus in regard to copper iron is electro-positive; in regard to zinc it is electro-negative.

The same principle holds good in the case of frictional electricity. Rub a glass rod with a silk handkerchief, the glass is electrified positively, the silk handkerchief negatively.* Rub the same glass rod with a fur, it is the fur which is now electrified positively, the glass is electrified negatively; the order is reversed, but the double action is maintained.

The same reciprocal action manifests itself in like manner in the electric machine, where we have the electric fluid generated partly by friction, partly by the decomposition of the amalgam which is smeared over the rubber. The silk rubber becomes electrified negatively, the glass cylinder or plate positively.

The terms *positive* and *negative*, as applied to electricity, may be taken, therefore, as expressing two corresponding manifestations of electric power; and to the question whether there are two different kinds of electricity or only one kind, the answer may be given that electricity is one in its nature, but in its action dual. A body when electrified has a power developed in it of attracting certain other bodies, and develops in them a similar power of attraction. But though this power is always one of attraction and not of repulsion, it acts differently in different cases, according to the nature and condition of the matter in which it is developed.

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* If the silk handkerchief be not insulated, *i.e.* kept from touching any conducting substance, the negative electricity will pass away unobserved to the ground.

LECTURE II.

THE ACTION OF ELECTRICITY.

The power exerted by an electrified body one of attraction, not of repulsion—Electric induction explained.

I HAVE said that a body in an electric state exerts a power of attraction, and not of repulsion. There are many facts that may be brought forward which at first sight would appear to contradict the statement here made; but there are none, as far as I know, which will not be found upon examination to harmonise with it. It will be well if I proceed at once to justify what I have asserted. To give an instance, an excited brass ball (it must be insulated to retain its excitation) and a pith ball are attracted together by a force which increases in the inverse ratio of the square of the distance of the two bodies from one another (Fig. 1).* The space, however, through which they move towards each other will be affected by the simultaneous action upon them of the law of gravitation. When the two bodies are brought into contact, the work begun by induction through the medium of the air will be completed by conduction, the electricity of that body which is most powerfully excited being equally diffused over both.* After a short time, however, the two bodies, though still retaining their electrical excitation, will again separate, the one being apparently repelled by the other. What is the explanation of this fact? The explanation usually given is that bodies endowed with opposite electricities attract each other, while bodies endowed with the same electricities repel each other. The two bodies, viz. the brass and pith balls, had in the first instance opposite electricities, and they therefore attracted one another; they have now the same, and therefore they repel one another.

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* This law of the increase of electric force does not apply in the case of any substance which has already reached the maximum of electric tension of which it is susceptible.

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* An excited body is said to act inductively upon another body when the two are not brought into actual contact, but are within the range of one another's influence. They are said to act conductively when they are either in actual contact one with the other, or are joined together by some intermediate conducting substance which is in actual contact with both. Heat in the same manner passes to bodies at a distance by radiation and connection, which correspond to electrical induction. It travels through a body from one end to the other, or from one body to another which is joined to it, by conduction. The heat, at first partially communicated through the air or other medium which intervenes between the two separate bodies, becomes equally diffused through both when they are united together. There is, however, in one respect, a marked difference between the way in which a body acts when it is raised in temperature and the way in which it acts when charged with electricity. A heated body coming in contact with a body that is colder does not at once divide its heat with the latter, or if it touch the earth part with it in an instant; whereas the effect which is produced when an electrified body is brought into connection with a non-electrified body, or with the earth, is of this instantaneous character. The cause, however, of this difference is obvious: heat penetrates the substance of bodies, and is not confined to their external coating; electricity lodges only on the surface of bodies. When, as in the Leyden jar, the electric fluid penetrates ever so little beneath the coating of the glass, it is not all drawn off at once by a single discharge.

This phenomenon admits, however, of a different interpretation. When the two bodies are brought into contact with one another, the work, as I have said, which was begun by induction is completed by conduction, and the two bodies pass into the same electric state. What is the consequence of this? The two balls begin now to exert a joint influence and attraction upon all the bodies around them. What then will be their mutual action upon any body which is presented on the side of the pith ball? Both will be drawn in the direction of that body, but the pith ball being, as we shall see presently, impelled by a relatively greater force, and the law of gravitation opposing less impediment to its movement, it will project itself a proportionate distance in advance of the brass ball in that direction in which their joint electricity flows.

You may say, perhaps, it is not easy to understand how the pith ball, having been once brought into contact with the brass ball by force of attraction, should afterwards recede from it, whilst attraction still continues to exist between them the same as before—the fragment of rock which has fallen from the overhanging mountain into the valley below, though it may be still, in some degree, attracted by the mountain above, does not loose itself again from the hold which the influence of the earth has upon it to go back to its former position. I cannot satisfactorily reply to this objection, without assuming at present that which in a future lecture I shall have to prove, viz. that electric force is the result of chemical attraction, which, you are aware, acts altogether differently from the attraction of gravitation. By the law of gravitation, all the atoms of which the fragment of rock detached from the side of the mountain is made up will continue to be attracted to the earth with undiminished force. The fragment therefore will remain immovable upon the earth's surface. But chemical attraction between bodies which have an affinity to one another acts, as I have said, differently; for either the bodies are resolved into their primary elements—in which case those elements which have the strongest attraction to one another recombine and give birth to new substances, leaving the other elements to be acted upon simply by the law of gravity—or these bodies are not resolved into their constituent elements, but retain the integral form they had before; and in that case the chemical attraction exerted by the one body on the other is confined to their surfaces, or rather, in the event of one of the two bodies being non-conducting, this attraction is confined almost exclusively to the side of the non-conducting body which is opposite the other body. It is not until the two bodies come into immediate contact that the electric excitation of the one most powerfully electrified spreads itself over both alike. Then the two bodies will act no longer as two bodies, but as two parts of one and the same body. Let me explain this by an example. Suppose an insulated brass cylinder be brought near to a positively excited brass ball (Fig. 2), the surface of the cylinder throughout will be excited, the end next the brass ball being electrified negatively, the end farthest removed from it positively. But if, in place of the brass cylinder, which is a conductor, a pith ball, which is a non-conducting substance, be presented to the charged ball, the side of the pith ball turned towards the brass ball will be electrified negatively, while the side turned away from it will be at first little or not at all affected. When, however, the two balls are brought into actual contact, and the electricity of the brass ball diffuses itself over the pith ball, the latter will be found to be positively electrified on the side turned away from the brass ball. I will proceed now to point out the cause of these facts, viz. why it is that the end of the cylinder and the side of the pith ball turned towards the positively excited brass ball are electrified negatively, and the other end of the cylinder and side of the pith ball are electrified positively. Afterwards it will be easy to explain what follows, viz. the recession of the pith ball from the brass ball after coming into contact with it, and certain other movements of electrified bodies which give countenance to the theory that like electricities repel in the same manner as unlike electricities attract each other.

When a body is formed of two elements chemically combined, one of the two elements is found to be positive, the other negative in relation to each other. For instance a molecule of water is formed of two distinct elements, viz. hydrogen and oxygen, combined together. The hydrogen is positive, the oxygen negative. Again, a molecule of brass is composed of two distinct elements, viz. zinc and copper. The former of these is positive, the latter negative in relation to each other; for it is to be observed there are elements in relation to which zinc is found to be negative: elements, in like manner, in relation to which copper is positive. When a substance is formed of many elements, either simple or compound, a certain number of these are positive, the rest negative. Thus, in the case of the pith ball,* such elements as carbon, oxygen, hydrogen, nitrogen, all enter, in different compound forms, into its substance. They are in relation to one another some positive, others negative. What then do we conclude from the fact of a body, *e.g.* a brass ball, being positively excited? We understand that the zinc which is the positive element of the brass ball is either alone in a state of excitation, or at all events is excited in a higher degree than the copper, which is the negative element in the composition of this metal. We infer, therefore, that the zinc element of the brass ball, by reason of the excited state in which it is, is rendered capable of acting to some extent independently of the copper element with which it is associated, and of exerting upon the bodies around it some portion at least of those powers which belong to it when out of composition. If then an insulated brass cylinder be brought near to a positively excited brass ball, what will follow? The positive element of the brass ball will act upon the negative element, viz. the copper, of the cylinder for which it has an affinity. The end of the cylinder opposite the brass ball will therefore become negatively excited, and the two bodies will be drawn towards one another by virtue of the attraction of affinity existing between them. The excited zinc element of the brass ball will act, however, not only upon the copper element of the cylinder, but also upon the zinc element, although in a different manner. The copper element, which is chemically heterogeneous, it will throw into an electrical state opposite to its own. The zinc element, which is homogeneous to itself, it will put into an electric state similar to its own; and, by means of this homogeneous element thus excited, it will be capable of operating also upon other more remote bodies which have elements of affinity to itself. We have then, first, negative electricity, the result of the zinc element of the brass ball acting upon the copper element of the cylinder. This negative electricity will reach from end to end of the cylinder, supposing it be a conductor. It will be strongest at the end nearest to the ball, weakest at the end farthest from it, because it is due to the attraction of affinity existing between the cylinder and the ball. We have also positive electricity throughout the cylinder. This, however, will be weakest at the end nearest the ball, and strongest at the end farthest from the ball, which is the end nearest to those bodies for which it has an attraction of affinity. But, though these two electricities extend from one end of the cylinder to the other, each one of them will make itself manifest at that end alone at which it predominates over the other, the point near the centre of the cylinder, where the two electricities are equal in force, being neutral.

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* Organic matter is composed of many elements, and for this reason is, as a rule, a bad conductor.

It is true I have not yet brought forward any facts to prove that electrical and chemical action are the same in origin and differ only in degree. Even so it cannot be thought unwarrantable to infer that, if a substance brought into actual contact with another exerts upon it a chemical influence, it will, if brought into such close proximity with another as to be able to act upon it through the medium which lies between them, exert an influence similar in character although less in degree. Neither can it be thought unreasonable to insist that when a substance brought into actual contact with another acts differently upon the different elements of which that substance is composed, so in like manner, if brought not into actual contact but still within the range of the influence of another substance, it will, so far as it acts, act differently upon the different elements which that substance contains. Potassium, for instance, when thrown upon water rapidly combines with the oxygen element contained in it, and liberates the hydrogen element in a nascent or electric state; in other words, in a state in which its power of combining with substances for which it has an affinity is highly developed. Zinc thrown into water acts in a similar way, but acts very much more slowly than potassium does. If then a brass ball, having the energies of its zinc element highly excited, be brought so near to a brass cylinder as to be able to exert an influence upon it, should we not naturally expect to find that it would act in one way upon the heterogeneous (the copper) element of the cylinder, for which it has an affinity, and in another way upon the homogeneous (the zinc) element, for which it has no affinity, but which is a conducting substance in relation to it? Whether the excited zinc element of the brass ball will act upon the homogeneous (the zinc) element of the cylinder directly or only indirectly—viz. through the medium of the copper element chemically combined with the zinc in the brass cylinder for which it has an affinity—this is a point I do not pretend to determine. Some, perhaps, would be more willing to admit that one body might act upon another as a whole, through the medium of that element for which it has an affinity, than separately upon the different elements of which that body is composed. This latter supposition would appear to them inconsistent with the nature of a body which has its constituent parts welded together by chemical combination.

You will have observed that I have as yet taken no account of the action of the copper element of the brass ball. The reason is this: when the brass ball is positively electrified we have no certain proof that the energies of the copper element are at all excited; but admitting it as the more probable supposition that the energies of the copper element are in some degree excited, and also that to a proportionate extent they neutralise the action of the zinc, still, the energies of the zinc element being altogether in the ascendant, we may safely confine our attention to them. I have said that the excited zinc element of the ball, in so far as it acts upon the homogeneous zinc element of the cylinder, will have the effect of putting the latter electrically in the same state in which it is itself, and will thus use it as a conductor, so as to operate by means of it upon other bodies more distant which contain in their substance elements for which it has an affinity. The truth of this statement will not be disproved by alleging that, if the cylinder consists of one element only instead of two, we shall still have the same two electricities produced which we have at present, viz. the negative at the end of the cylinder nearest the brass ball, and the positive at the end farthest from it. This only shows that one element alone, provided it be a good conductor of electricity, is capable of discharging the double function which has to be performed, although that double function will be much more efficiently discharged where we have two different elements to accomplish each its own special part. If you suppose, for instance, the cylinder to be of copper, in that case the end nearest the brass ball would be negative, by reason of the action of the excited zinc element of the brass ball upon the copper—the one having an affinity for the other, the copper being negative in relation to zinc. The end farthest from the brass ball would be positive, because, the cylinder being a conductor, the excited zinc element of the brass ball would act not only upon the copper cylinder itself, but through the cylinder upon the negative elements existing in the bodies which lie beyond it. On the other hand, if we suppose the cylinder to be made of zinc, we should, in the first place, have the end of the cylinder farthest removed from the ball positive, because the positive electricity of the ball, transmitted through the homogeneous element of the cylinder to its extreme point, would there act upon such negative elements as were contained in the bodies lying beyond. Should none but homogeneous elements be found in those bodies which were near, it would, by means of these homogeneous elements which are conducting in its regard, travel farther, until it did come to elements upon which it could act chemically. We should, in the second place, have the end of the cylinder nearest the ball negative, because the electric current proceeding from the bodies beyond the zinc cylinder (in which we have supposed negative elements to have been roused into activity) would not be arrested in its course before it reached the end of the conducting cylinder opposite to the brass ball. You have already had the fact brought before you that, when a conductor intervenes between two bodies which are in an active electric state and have an affinity to one another, there is always a current of electricity running both ways; or, in other words, a twofold electric action—one positive, the other negative—exerted upon all the intermediate parts of the conductor, but manifesting itself most conspicuously at the two ends. Now, in the case supposed, the zinc cylinder would be a conductor between the charged ball and the body brought by the conducting cylinder into communication with the charged ball, and there would be therefore a current flowing both ways upon this conductor; but as in this case one of the two bodies would be in no more than an induced electric state, it is hardly necessary for me to observe that the amount of electricity transmitted through the intervening cylinder would, under the circumstances, be very small, and its manifestation very feeble.

You may, perhaps, have found it difficult to follow my explanation of the complex action which takes place between the charged ball and the insulated cylinder brought under its influence. And yet, in reality, the whole of the action here described, complicated though it may appear to be, is simply the working out of a well-known law, viz. that of the attraction of affinities. By virtue of this law the positive (the zinc) element of the brass ball—supposing the brass ball to be positively electrified—acts upon the negative (the copper) element of the brass cylinder, which is chemically heterogeneous to itself. It puts it into an electric state which is opposite to its own. Consequently the end of the cylinder next to the brass ball shows negative electricity. The zinc element of the brass ball acting at the same time, either directly or indirectly, upon the homogeneous zinc element of the brass cylinder, puts it into an electric state similar to its own. Homogeneous elements, though they have no chemical affinity one for another, are capable of transmitting electrical influence. Hence the positive (the zinc) element of the brass ball, though it has no attraction of affinity for the positive (the zinc) element of the brass cylinder, uses it nevertheless as a conducting medium which puts it in communication with other bodies for which it has an affinity. It is thus—by the operation of the same law of the attraction of affinities—that the cylinder shows negative electricity at the end nearest the positively excited ball, and positive electricity at the end farthest from it, or at whatever other point upon the surface of the cylinder a body which contains elements of affinity to the positively excited brass ball is made to approach.

It may be said, if this theory were correct we should have the positive (the zinc) element of the induced cylinder reacting upon the negative (the copper) element of the inducing brass ball, because it has an affinity for it, and also is in close proximity to it. There would seem to be no sufficient ground for supposing that one element will act upon another by affinity indirectly, while it is at the same time acting upon it directly. The positive element of the brass ball does act upon the negative element of the same ball directly, the two elements being chemically united together in one substance. The former communicates to the latter whatever electrical energy it is, under the circumstances, capable of receiving. It then communicates to the bodies around the surplus which still remains free and unabsorbed; and this surplus energy it expends, in the first instance, upon those elements in the bodies immediately around which have an affinity to it; next, upon those elements in these same bodies which, though they have not themselves any affinity to it, yet serve to bring it into connection with other more remote bodies which have an affinity to it. If, however, the supposition be made that electric energy is communicated by the positive element of the brass ball to the homogeneous element of the brass cylinder in so great a quantity that it has not a sufficient outlet to carry it away, so that it becomes converted from current into statical electricity; in that case I should expect to find that the positive (the zinc) element of the cylinder would become, like the positive (the zinc) element of the ball itself, a source of electric power acting on all the bodies around it.

I will here notice one or two facts which have a claim upon our attention, as serving to illustrate the mutual action which takes place between the charged ball and the induced cylinder. When the charged ball is withdrawn from the insulated cylinder, all trace of negative electricity at the end of the cylinder nearest the ball, and of positive electricity at the end farthest from it, at once disappears. When, on the contrary, the end of the cylinder farthest removed from the ball is brought into connection with the earth, the negative electricity of the end nearest the charged ball is increased, whilst the positive electricity which showed itself at the other end is no longer discernible there. But if the connecting link by which the cylinder is joined to the earth be broken, and the charged ball be at the same time taken away, the cylinder is then found to have negative electricity diffused over the whole of it. These phenomena are not different from what, under the supposition of the truth of the theory I am advocating, we should expect to find. The charged ball being withdrawn, the effects which it produced in the cylinder, viz. negative electricity at one end and positive electricity at the other end, naturally disappear. The negative element of the cylinder is no longer attracted by the excited positive element of the ball to the end opposite to it, and the positive element of the cylinder no longer serves as a conductor whereby the charged ball acts from the farthest end of the cylinder upon those objects that lie beyond it; and whatever may remain of former electrical excitation in the cylinder ceases to make itself apparent after the charged ball has been taken away, because the two electricities are no longer drawn to the opposite ends of the cylinder, but, being diffused over its whole surface, they neutralise one another's action. In the second case, where the charged ball is not withdrawn, but the end of the cylinder farthest from it is connected with the earth, the negative electricity of the end of the cylinder nearest the ball is more strongly developed. The reason of this is that the electric force now converges upon that point from a more widely extended area. But no positive electricity is discernible at the opposite end of the cylinder, connected with the ground, the fact being that the cylinder and the earth form now, electrically speaking, one body; and therefore the whole of the cylinder now stands, in regard to the charged ball, in the same relation in which that part of the cylinder which was nearest to it did before, wherein, as you may remember, negative predominated over positive electricity. If, then, under these circumstances, the connection between the cylinder and the earth be broken, and the charged ball be simultaneously withdrawn, it is easy to see what will follow. Negative electricity being strongly developed in the now insulated cylinder, and the amount of positive electricity, on the other hand, being comparatively small, when they have diffused themselves over the whole surface the cylinder will be found in a permanent state of negative electricity. There is in these effects which take place between the charged ball and the insulated cylinder nothing, I say, which does not admit of being readily explained in accordance with the theory upheld by me.

Let us now suppose the pith ball, instead of the insulated cylinder, to be brought under the influence of the positively excited brass ball. The pith ball is a bad conductor, and therefore, until the two bodies come into contact, almost all the action of the brass ball upon the pith ball will be confined to that side of it which faces the brass ball. The zinc element of the positively excited brass ball will act upon those elements in the pith ball for which it has an affinity. The side of the pith ball opposite the brass ball will be excited negatively, and the two balls will be drawn together by the force of the attraction existing between them. The excited element of the brass ball will act also upon the homogeneous elements of the pith ball, either directly or indirectly. If it acts upon the homogeneous elements of the pith ball only indirectly, *i.e.* through the medium of the heterogeneous elements with which they are chemically combined in the same body, it seems probable that the effect produced upon them before the two bodies come into actual contact will be very partial, the electric energy imparted to the heterogeneous elements being expended primarily on the drawing of the two bodies together. So far, however, as the brass ball does act upon the homogeneous elements contained in the pith ball, it will make use of them as a conductor, whereby it will bring its influence to bear upon other bodies around for which it has a chemical affinity.*

When the two bodies are united by actual contact the positive electricity of the charged ball will be diffused equally over both balls. They will then form, electrically speaking, but one body, having the same kind of electricity spread over their entire surface, and having the same attraction. It may be that the pith ball is still drawn towards the brass ball by the force of the negative electricity of those constituents in it which are chemically heterogeneous, and which have an affinity to the positive (the zinc) element of the excited brass ball. I say this may be the case, because it is possible that when the positive electricity of the homogeneous elements of the pith ball has become paramount, the negative electricity of the heterogeneous elements which are chemically combined with them may be absorbed and neutralised. But granting that the pith ball still continues to be drawn towards the brass ball by the affinities of its excited heterogeneous elements, it is certain that it will be drawn more powerfully the other way by the combined operation of the affinities of its own homogeneous elements acting in union with the affinities of the excited ball; for the electric current which proceeds from the brass ball to those bodies which lie beyond the pith ball will of necessity first converge upon the pith ball in its passage to them. Now we find, when the current of the galvanic battery is thus concentrated upon the attenuated carbon points of the electric light, the energy with which it acts upon them is so strong as to disintegrate the substance of the carbon, and to cause particles of it to fly off from the positive to the negative terminal. It cannot then be a matter of surprise to us that the current of electricity from the brass ball, converging upon the smaller and lighter pith ball, should cause it to project itself a proportionate distance in advance of the brass ball, in the direction of its current.

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* It will be observed I speak of the elements in the substance of the pith ball as being heterogeneous or homogeneous to the zinc, according as they have, under the circumstances, an affinity to it or not. Between zinc and carbon, when both exist in a simple state, it may be said that there is affinity. They are found commonly enough combined together. They are then heterogeneous elements. But between zinc and carbon, when the carbon is under the form of carbonic acid, or, in other words, when it is combined with oxygen, there is no affinity. Zinc being heterogeneous with oxygen, and carbon also being heterogeneous with oxygen, both have an affinity to oxygen, whilst, as far as they act through its medium upon one another, they will act as if they were homogeneous elements.

Once you clearly understand how it is that the pith ball is first drawn to the excited brass ball by electrical attraction, and is afterwards separated from it, not in consequence of attraction being converted into repulsion, but by virtue of the same law of attraction acting under a change of circumstances, and you will easily be able, by the law of chemical attraction, to interpret all the other movements which take place in bodies under the influence of electricity, without having recourse either to the hypothesis that there are two distinct kinds of electricity, or to that other hypothesis that unlike electricities attract, like electricities repel, one another. Thus a positively electrified pith ball will attract an unelectrified pith ball for this reason, because in the one there are elements in a state of activity and energy which find in the other elements for which they have an affinity. Again, a positively electrified ball will attract a negatively electrified ball with still greater force, because it not only finds in the latter elements for which it has an affinity, but it finds those elements in an active, energetic state. On the other hand, two balls positively excited, and in like manner two balls negatively excited, will not attract each other; because in both these cases the homogeneous elements contained in each are excited, and homogeneous elements have no affinity towards one another. Neither will the excited homogeneous elements of the one ball be able to act upon, so as to attract to itself, the heterogeneous elements of the other ball; because in each the action and energy of the homogeneous elements are in the ascendant, and will prevail over the action and energy of the heterogeneous elements which are chemically conjoined with them. The two balls, instead of being attracted towards each other, will be attracted towards other bodies, and therefore will exhibit towards each other a virtual repulsion. Thus two pith balls, suspended side by side from the positive end of the excited cylinder (Fig. 2), will be attracted towards bodies that are in a neutral or in a negative state in regard to that end of the cylinder. The ball on the right will naturally absorb to itself the attraction of the bodies on the right which are in this state, and will be drawn towards them. The ball on the left will, in like manner, absorb into itself the attractive influence of bodies on the left in a contrary state, and will be drawn to them. The consequence will be that, whilst they are only acting in obedience to the law of attraction, by which they are drawn to bodies to which they have an affinity, they will appear to repel one another. I do not deny, however, that they will exert one upon the other a certain amount of propulsion. The two similarly excited balls are conductors of electric force in respect to each other. The ball on the right will act upon all the bodies on the left coming within the range of its influence, through the ball on the left, and will cause it to project itself farther in that direction. The ball on the left will act in the same manner upon the ball on the right, and thus the distance between the two will be still farther increased. But this is nothing more than the action which takes place between the charged brass ball and the pith ball, when, after being attracted together, they separate from each other. It is the effect not of any repulsion which these bodies have one to the other, but of the attraction which they have to other bodies.

LECTURE III.

ELECTRODYNAMICS.

The doctrine set forth and explained in the preceding lecture supported by facts—The laws of electrodynamics investigated.

IT is so generally held that in the same way as electricities of unlike sign attract, so electricities of like sign repel one another, that it may be well that I should bring forward some facts which are plainly at variance with this rule, and accord with the doctrine which has been laid down in the last lecture. Afterwards I shall proceed to examine what are called the laws of electrodynamics, for the purpose of showing that they are not really but only verbally opposed to the conclusions I have drawn.

It is, then, a well-ascertained fact, and one which is recognised to be in accordance with electrodynamic laws, that when parallel electric currents flow near each other in the same direction, the currents themselves, and the wires along which they run, attract instead of repelling one another (Fig. 5). The true explanation of this is that the current which flows along one of the conducting wires to the negative element in the cell of its own system is attracted at the same time by the negative element belonging to the other system, with which it is brought into connection by the proximity of its conducting wire. Thus two wires under the influence of like electricities are drawn together. We have a still more striking example of the same thing in the case of two solenoids,* the current of one of which flows from right to left, and the current of the other from left to right. If the two positive or the two negative ends are brought near together, it will be found that, instead of repelling, they will attract one another. The reason of this is the same which has already been given to account for the attraction of two currents running along two neighbouring wires in the same direction. I shall have occasion, later, to notice the similarity of the action of the magnet to that of the solenoid, in consequence of the fact that both alike have a current flowing round them from end to end. At present I refer to the solenoid only for the purpose of showing that we cannot affirm that electricities of like sign repel, and those of unlike sign attract one another. When brought within the range of one another's influence, electricities of like sign act through each other upon those unlike elements for which they have an affinity. How they will do so—in other words, what effect they will produce upon each other's movements—will depend upon the direction in which those unlike elements for which they have an affinity, and to which they tend through the medium of each other, happen to lie.

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* A solenoid is a combination of a rectilinear with a sinuous current (Fig. 4).

I have referred to one of the recognised electrodynamic laws as being in contradiction to the doctrine which affirms that like electricities repel one another, and in harmony with the theory which identifies the action of electricity with chemical attraction. I proceed now to consider the other electrodynamic laws in succession. None of them, you will see, conflict with our theory concerning the action of electricity. But this theory will, on the contrary, be found to furnish the most satisfactory explanation of these laws.

The first of these laws affirms *that the successive portions of a rectilinear current repel one another.* I should wish to change one word, and say that the successive portions of the same current *propel* one another. The effect produced will, of course, be precisely the same whether it be caused by propulsion or by repulsion; but, as it seems to me, it is propulsion which must be admitted to be the cause of the effect which here takes place. We have seen that the pith ball, after it has been in contact with the charged ball, is projected forward in the direction of the current which flows from them. This is, as I have said, a natural result of the attraction which exists between the positively excited elements of the electrified brass and pith balls and the negatively excited elements of those bodies on that side which are brought under their influence—the brass ball acting electrically on those bodies through the pith ball, which it propels towards them. In the case of the electric light we find particles of carbon in a volatilised or an incandescent state propelled from the positive to the negative terminal. We learn also, from the spectrum analysis of the spark of the electric machine, that molecules detached from the metallic knob of the conductor pass off in a volatilised state. It is, then, quite in accordance with these and many other well-known facts, that the successive portions of a current should exert a propelling power upon each other, although no particles can be detached, except either their connection with the body of which they form part be but very slight, or the strength of the current which passes over them be very great.

The second rule is *that parallel currents flowing in the same direction attract, flowing in opposite directions repel one another*. I have already considered the first part of this rule, viz. when parallel currents flow in the same direction. Each current will in that case be attracted not only to the negative element in its own system, but also to the negative element of the system with which it is brought into connection by the proximity of its conductor. The particles of the one conductor along which the current passes will consequently be drawn to some extent towards the neighbouring conductor, *i.e.* to that extent which corresponds to the force of the attraction exerted through it. This attraction extends, of course, along the whole length of the two parallel lines, but it may be sufficiently indicated by a line drawn from one particular point of one of the conductors to a corresponding point in the other (Fig. 5). The second part of this rule states that parallel currents flowing in opposite directions repel one another. In this case, as in the preceding, each current will, by reason of the proximity of the two conductors, be attracted, not only to the negative element of its own system, but also to the negative element of the system contiguous to it. But in consequence of the two negative elements, by which the current is simultaneously attracted, lying in opposite directions, the current becomes divided, and, whilst the far greater part of it continues its course along the conductor which leads to the negative element of its own system, a certain portion of it is drawn out of its own course into that of the neighbouring current. The circuit which will be made by this portion, under the influence of the attraction of the opposite current, until it at last merges itself into it, is represented in the diagram (Fig. 5ⁱ) by a curve line drawn from the one conductor to the nearest point of the other. In reality, however, this mutual attraction being exerted at every point along the parallel wires, each wire will, in some degree at least, incline in the direction of the current which is drawn out of it. Hence the effect produced will be the same as though the two currents actually repelled one another.

The third rule is *that angular currents, when they both flow towards the crossing point, or both flow from it, attract: but that when one flows towards the point of crossing, and the other flows from it, they repel one another.* In Fig. 5ⁱⁱ, AO and CO, and in like manner OB and OD, attract one another. The reason which I have given in explanation of the first part of the preceding rule, showing why parallel currents running in the same direction attract, applies just as much to the case of angular currents running to the same crossing point. The positive current AO will act in some degree upon the negative element, which is brought under its influence by the proximity of the conductor CO. When AO and CO form an acute angle, the two currents passing along them being brought more closely together, will act more powerfully upon one another than two parallel currents. But should AO and CO meet so as to form an obtuse angle, the two currents will still exert some degree of attraction upon one another. It is true that in this case the attractive force will have to make a circuit to pass out of one conductor into the other, but, as it will make this circuit without going out of the space included between the two conductors, it will not separate them, but will still tend in some degree to draw them nearer together (Fig. 5). On the other hand, AO and OD (Fig. 5^{ii}), and in like manner CO and OB, are said to repel one another. The reason which was given in explanation of the second part of the preceding rule, showing why there is an apparent repulsion between two parallel currents flowing in opposite directions, applies to the case of cross currents where we have one flowing to and the other flowing from the point of intersection. The current of AO will be attracted to the negative element of the neighbouring system, with which it is brought into connection through the conductor OD. But inasmuch as the conductor OD has already a positive current flowing along it to its negative term, the positive current of AO will not be able to act through it upon its negative element except by making a circuit so as to fall into the current of OD, upon which it will then exert a propelling power. The conductor AO being drawn in consequence, in some degree at least, in the direction of the current which passes out of it, AO and OD will appear to repel each other, although in reality the one is acting through the other by attraction. It is in accordance with this rule, above given, that a bent line (Fig. 5^{ii}, AOD) along which a current is passing has a tendency always to straighten itself.

The fourth rule tells us that "*when one current is perpendicular to another, the former current, if movable, will be carried backwards in a line parallel to the latter if the former current runs towards the latter, but will be carried forwards in a line parallel to the latter if the former current runs from the latter.*" It will be sufficient to consider one of these alternatives. In explanation of this rule, which is dependent upon those which have gone before, it is usually said there will be attraction between the currents of AB and DE (Fig 5^{iv}), and repulsion between those of DE and BC; and these combined influences will cause DE to move backwards in a parallel line in relation to AC. According to my representations there is attraction between the currents of DE and BC, as well as between those of DE and AB. As it is plain, however, that the current of DE must make a circuit in order to fall in with the current of BC, and that in doing so it will draw the conductor DE in the same direction, DE will necessarily be drawn away from BC. The current of DE will likewise have to make a circuit in order to merge itself in the current of AB; but, as will be seen, the direction which the current will take in making that circuit will carry DE towards AB. The result, therefore, will harmonise with the rule laid down, though it be brought about by attraction alone.

It may be added as a corollary, which is deducible from the preceding rules, *that if two currents, of which one passes along a conductor which is capable of revolving round one of its ends as upon a pivot, and the other is a rectilinear current, be brought near one another, the former current will rotate continuously in the opposite direction to the latter* (Fig 5^v). It is necessary, however, in order that the conductor DE may move round as a radius describing a circle, that it should not be too long, or it would be carried altogether out of reach of the influence of the rectilinear current.

It is to be observed that all these electrodynamic laws are the expression of one principle; but this one principle, when brought out in action, produces results as manifold and dissimilar as the circumstances under which its action takes place. The principle which shows itself in these varied results is that unlike electricities attract one another; and a necessary consequence of this is that like electricities exert a propelling power one upon another. It must not, however, be supposed that this is equivalent to saying that like electricities repel one another.

When it is said that like electricities repel one another, it is meant that they do so of their own nature, in the same manner as unlike electricities attract one another. But when we are told that they propel one another, we are given to understand that the force which they exert is called into action by some cause which lies out of themselves, viz. that attractive force which unlike electricities exert upon one another through them —all electric action being in fact founded on chemical attraction.

LECTURE IV.

THE ELECTRIC MEDIUM.

The action which takes place in the medium between two electric bodies considered.

THE importance of the point discussed in the last two lectures, in its bearing upon our knowledge of the true character of electricity, must be my excuse for dwelling so long upon it. Before quitting this subject I wish to add a few words concerning the medium through which two currents or two electric bodies, though separated, have power to act upon one another. All induction depends, in reality, upon the action which takes place in this medium, even when the medium is said to be a non-conducting substance; so that, if there were no substance at all intervening between two bodies, we have reason to believe that in that case no induction at all would take place between them, because there would be no pathway open by which electricity could pass from one body to the other.

In speaking of the medium interposed between two electric bodies, I put aside the case where the entire space between them is filled up by a solid body. By such a medium the two bodies may more truly be said to be conjoined together than to be separated from each other. Even the worst conducting of solid bodies is a better conductor than the air or any other gaseous substance,* which, as far as we know, have all of them practically the same specific inductive capacity.

Confining my attention then to media which consist of substances in a gaseous or a fluid form, I proceed to observe that all elements are, in a greater or less degree, electro-positive or electro-negative; and that therefore all media containing in them elements which are electrically homogeneous with either one or the other of the two bodies will serve as a conductor between them. If the medium be a simple fluid substance, *e.g.* mercury, able to transmit readily whatever electricity is communicated to it, no transposition of its particles need take place. If, on the other hand, the medium be a gas or fluid, the particles of which are capable of moving readily enough, but not capable of easily parting with the electricity which they have received, the current of electric force passing through it from the one body to the other will become a current of air-particles or of fluid-particles charged with electricity. Oil of turpentine is, for a liquid, a bad conductor. In a vessel filled with this oil let two brass balls be suspended, the one being connected with an electric machine, the other with the earth. On turning the machine, the ball which is connected with it will become positively electrified; the other ball will become, by induction, negatively electrified. Let shreds of sewing silk, a non-conducting substance, be mixed with the oil of turpentine. They will be found to attach themselves together by their extremities in such manner as to assist the transmission of electricity from one ball to the other. If by the working of the machine the excitation be increased, a visible current will be set in motion, the particles of oil in contact with the positively excited ball being rapidly carried along in a stream to the negative ball.* Now that which takes place under our eyes in the oil of turpentine takes place in like manner, we have a right to infer, in the air, or in any other gaseous medium which intervenes between an electrified body and another body which is acted upon by induction. If the electric force passing from one body to the other be but slight, the particles of the air may be able to carry it away imperceptibly; whereas, if it be considerable in amount, the effect which will be produced will be made manifest. Thus, if a metallic rod terminating in a point be attached to the conductor of an electric machine, electricity will escape from the point in large quantities. The consequence will be that the layer of air in front of the point will be electrified by contact, and projecting itself forward—like the pith ball which has been electrified by contact with the charged brass ball—will give place to other portions of air, which will be acted upon in the same manner; thus a continuous current of air will be kept up, which will be perceptible to the hand, and will produce a visible effect upon the flame of a taper brought near to it (Fig. 6).

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* In proof of the statement made above, the following experiment may be cited. Let a small electric charge be communicated to a metallic disc, and let the disc be suspended rather more than an inch above the cap of a gold-leaf electroscope, the leaves of the instrument will immediately diverge to a certain extent by induction. Now let a plate of shellac, about an inch in thickness, and mounted on an ivory handle, be inserted between the electrified disc and the cap of the electroscope, the divergence of the gold leaves will immediately increase, showing that induction takes place more freely through the shellac than through air.

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* Dr. Kane's "Chemistry," chap. iv. sec. 1.

It is manifest then that the power which one body has of inducing electricity into another body depends in the first place upon the amount of the charge which has been communicated to the electrified body; next upon the proximity of the one body to the other; and thirdly upon the inductive capacity of the medium which intervenes between them. We are not, however, to suppose that the electrified body is a centre from which rays of electricity proceed only in straight lines. As I have already said, from a powerfully charged body a current of electrified air-particles passes away. In whatever direction those particles are transported the electrified body will exert its inductive power. Let A be a body positively charged (Fig. 7). Let PP (a plate of metal fixed upon a glass stand and connected by a chain C with the ground) be placed in front of A. The face of PP turned towards A will be negatively charged by induction. The back of the plate PP will show no signs of electricity, because the positive electricity of PP will descend by the chain into the ground. If now we hold B (a ball provided with an insulating handle) immediately behind the middle of PP, it will show no signs of being electrically charged; it is not reached there by the current of electrified air-particles proceeding from A. But if it be brought near the edge of the plate PP, or if it be held a certain distance from behind the middle of the plate, it will receive a negative charge, because in either of these positions it is reached by the current of air-particles passing round the edge of the plate.

Again, it is not difficult to understand how a tube becomes when it is exhausted a better conductor of the electric current than it was before. In the exhausted tube the charged particles meet with less resistance in transporting their burthen from one end of it to the other. M. Gassiot effected a more perfect vacuum than the Torricellian. First, by means of the air-pump he exhausted a tube which had been filled with carbonic acid, and then by the aid of caustic potash he absorbed whatever residuary portion of gas was left behind. Through this tube, exhausted in this manner, no spark, no luminous discharge of any kind, could be made to pass. But though no luminous discharge can be transmitted through a tube so completely exhausted, we do not say that no electricity can pass through it, because it is found that when such a tube is placed between two conducting tubes connected, the one with the inner, the other with the outer terminal of an induction coil, there are reciprocating discharges made manifest in the conducting tubes, although there is none which is perceptible in the non-conducting tube. On the other hand, we are not justified in inferring from this experiment that electricity can pass where no material substance exists, because we have no proof that material substance of some kind is not still present in the tube;* and if there were no material substance whatever in the interior of the tube, it might still be possible for the electric current to pass along the interior surface of the vessel. What we can, however, rightly infer from these, as well as from other experiments which might be brought forward, is that the electric influence exerted by one body upon another which is separated from it depends upon the action which takes place in the medium which is interposed between them, even when that medium is said to be a non-conducting substance. I omit to say anything at present about the luminous effects which are oftentimes produced in this medium by the passage of the electric fluid, *e.g.* the light which is seen to play around the point of the discharging rod when it is looked at in the dark, and the visible glow which bursts out in the conducting exhausted tube. Hereafter I shall have a more fitting opportunity of speaking about these phenomena.

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* Rays of light, *e.g.* the flame of a candle, may be seen through a tube thus perfectly exhausted. Now, according to the most general received theory, light is the effect of a certain vibratory motion communicated to the ethereal medium, or the element of matter in its most attenuated form. It requires, therefore, the presence of matter as a necessary condition for its transmission.

LECTURE V.

THE NATURE OF ELECTRICITY.

Arguments for and against the theory of its being a material substance.

I HAVE discoursed at sufficient length in support of the opinion that there are not two kinds of electricity but only one kind, operating differently under different circumstances, but exerting always an attractive force. I proceed now to the consideration of the next question which comes before us, viz. what is electricity?

There are many who hold that electricity is a material substance. They allege in favour of their view the language used by all in speaking about it. It is called the electric fluid, the magnetic current. A vessel is said to be charged with electricity. They appeal also to facts. To accomplish a given amount of work, *e.g.* to transmit a message a certain distance along the telegraphic wire, there is need of a certain definite quantity of electricity, as distinguished from a certain intensity of action, which seems to favour the idea of its being a material substance. Again, put a vessel coated inside and outside with tinfoil, like a Leyden jar, under a glass receiver, connect the inside of the vessel with one end of an induction coil, and the plate on which it stands with the other. When by the use of the air-pump the vessel becomes sufficiently exhausted, you will behold a cascade of light flowing down the sides of the vessel like a liquid running over. Also the violent effects which electricity at times produces, such as the throwing down of high steeples, the rending asunder of the trunks of trees, seem to point to the agency of a material substance.

Others, on the contrary, refuse to believe in a material substance, no trace of the existence of which has ever been detected by the closest scrutiny, the most searching investigation. They take no exception to the terms electric fluid, magnetic current, and the like, inasmuch as electricity exhibits many of the properties and of the characteristics of a fluid, and obeys also many of the laws of a current. But then, they reply, it manifests other characteristics which do not accord with the hypothesis of its being a fluid. It lodges only on the external parts of bodies. Let a metallic hollow sphere divisible into two parts, and having a smaller metal sphere inclosed within it, receive a charge of electricity. Although metal is an excellent conductor of electricity, yet upon separating the two external parts from each other it will be found that the electricity has not penetrated beneath the surface. The inner sphere discovers no trace of electricity upon it. It is found, moreover, that for electricity to remain upon the external parts of bodies it is necessary there should be other bodies around upon which its powers may be exerted. Let a purse of fine gauze (Fig. 8) held distended by a rim of ivory or ebony, or some other non-conducting substance, receive internally a charge of electricity. The charge will be found present, not in the inside, but only on the outer surface, where only it can exert an influence on other bodies. By means of a non-conducting silk thread fastened to the bottom of the purse, let it be turned inside out, it will be found that the electricity has shifted its position at the same time, and still lodges on the outside. That the position which electricity occupies upon the parts of bodies depends upon the facility which those parts afford it of acting inductively upon other bodies, admits of being shown more conclusively still. For let an uninsulated ball be introduced within the purse, and immediately electricity shows itself within the purse as well as without, because the presence of the ball there now affords it an opportunity of exerting its energies on the inside as well as on the outside of the purse.* Facts like these tend to show that electricity is not a material substance, but a force residing in material substances, and ready upon the first occasion to pass into an active state.

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* I do not mean to say that absolutely no trace whatever of electricity will be found in the inside of a hollow vessel when it has an electric charge communicated to the outside of it. The air itself possesses a certain amount of electric capacity. This power it will have more opportunity of exerting if it has a free passage through the vessel. A hollow wire is not so good a conductor of electricity as one which is solid.

In reply to the argument on the other side, founded upon the fact that a certain quantity of electricity is required, *e.g.*, to work its way by the telegraph wire to a given station, it is sufficient to say that the same thing happens in the transmission of heat. A certain quantity of it is required to pass from one end of an iron rod to the other. Yet it is looked upon as certain that heat is not a material substance, but a molecular motion of the ultimate particles of bodies. The answer to the argument taken from the fact of electricity flowing in a cascade of light over the rim of the charged vessel which has been placed under the glass receiver, and brought into connection with the induction coil, is of the same kind. The air in its ordinary state, though not a good conductor of electricity, is nevertheless a conductor. But the highly attenuated medium which remains in the receiver after it has been to a considerable degree exhausted is a much better conductor than the air in its ordinary state. The passage of electricity through the air, when effected with a certain degree of velocity and energy, produces a spark, or the ignition of the gases of the air. Its passage under similar circumstances through a rarefied medium produces a silent luminous discharge. But from this we should not be warranted in drawing the conclusion that electricity is a material substance, since the same thing has to be said of light which has been said of heat, viz. that the generally received opinion is that it is not a material substance, but only a mode of motion amongst the ultimate particles of matter, differing from heat in no other respect but this, that its undulations are of less amplitude. I may add that many of the arguments brought forward to prove the immateriality of light are equally available to prove the immateriality of electricity. Thus we are told that light travels from the sun to the earth, a distance of more than ninety millions of miles, at the rate of nearly two thousand miles a second; and that, if a ray be made to fall upon one of the scales of the most sensitively constructed balance, the impact of the sun's ray, notwithstanding the inconceivable velocity with which it moves, does not affect the balance a hair's-breadth. Now electricity—which travels not in straight lines alone, as is the case with light, but in any path, however devious; which moves under special circumstances with greater velocity than light, and it may be under ordinary circumstances with the same velocity from the operation of the same causes—however powerful the attractive force which it exerts, however destructive the action of the mechanical and chemical powers which it sets in motion, raising up waterspouts at sea, overthrowing towers on land, has itself no momentum, which a ponderable body moving with such immense velocity would necessarily have. In this respect electricity and gravitation may be compared together. Bodies affected by the law of gravitation have a momentum proportioned to the mass of matter which they contain and the rate of velocity with which they move. In like manner bodies acted upon by electricity have a momentum proportioned to their weight of matter and the velocity of their motion. But neither gravitation nor electricity has any momentum of its own. Later, I may have occasion to point out that almost all the violent effects attributed to electricity are in reality produced by the immediate agency of chemical powers, called forth into action, it may be, by electrical influences.

These and many similar facts, of which some will be brought before you in the course of our argument, point very strongly to the conclusion that electricity is not a material substance, but, as I shall proceed to show, a force inherent in matter, arising from those attractions and affinities which in a greater or less degree all material particles are found to have one towards another.

NOTE.—The term *chemical affinity* is used to express the attraction which exists, by the constitution of their nature, between certain unlike elements, which when united together form a new substance. The attraction between oxygen and hydrogen may be taken as an example. Being united together, they form water. The terms of *attraction of cohesion, attraction of adhesion,* express that attraction which (proceeding, as the case may be, from internal or external causes) unites particles together which when united do not form a new substance. Thus the attraction of one drop of water to another, of one atom in a bar of silver to another, is that of cohesion; whilst the attraction of particles of a liquid to a solid body which has been immersed in it is an example of the attraction of adhesion. The attraction of a piece of wood glued to another, or of paper pasted to a wall, is of the same kind.

The explanation of terms here given is that which is commonly received. I will put before you a partially different view on this subject. In doing so, I do not wish to insist in any manner upon this particular division or classification, which I consider preferable, but am anxious to allot its proper place to electrical attraction.

All attraction, it seems to me, may be ultimately reduced to two kinds, which are distinct in themselves, although they may more frequently be found united together than separated one from the other. I speak of the attraction of gravitation and of chemical attraction—the former being that attraction which all particles alike have one to another by reason of their having in common the same material nature; the latter being that special attraction which some particles have to one another, and other particles have not, by reason of the difference of their original constitution. Electrical attraction, arising as it does out of the peculiar powers and properties with which bodies are endowed, is to be classed under chemical attraction, the distinction between them being one of degree rather than of kind. Thus when unlike elements are drawn together by their affinities, and combine one with another so as to form a new substance, this is said to be the effect of chemical attraction. When, on the other hand, unlike elements are drawn together by their affinities, but, from whatever cause it may be, do not unite together to form a new substance, this is said to be the effect of electrical attraction. This may happen in different ways. It may be that the action of the affinities of bodies which are attracted together is too feeble to give rise to any substantial union between them, as for instance in the case of the electrified brass ball and the pith ball. Or it may be that the substances do not act upon one another directly, but only through some substance which lies between them, as, *e.g.*, when the charged ball and the insulated cylinder act upon one another through the medium of the air, or when the oxygen and hydrogen elements of the liquid in the galvanic trough act upon one another through the medium of the conducting wire. Like elements do not, as a rule, exert any chemical attraction upon one another; they may, however, be drawn together by the operation of the same or similar causes. Thus by the combined action of the laws of electricity and gravitation mists are raised up from the ocean, and are massed together in the air in the form of clouds, and being converted into drops of rain fall upon the earth, and flow again to the ocean. Thus in the process of electro-plating the metal held in solution deposits itself upon the surface of the article suspended in the bath. This deposition is effected by a current of electricity being made to pass through the liquid from the one electrode to the other. But when by the force of electric attraction the atoms of copper or silver have been deposited so closely one upon another as to form a compact plate, they continue after all electric action has ceased firmly bound together by the force of gravitation. For the nearer two particles are brought together, the greater is the force with which the attraction of gravitation acts upon them. And, besides this, when the particles of which any body is formed are so closely and compactly welded together that no air can penetrate between them, the weight of the superincumbent and the pressure of the circumambient atmosphere tend to keep them bound together. When like particles joining together form one substance, and when unlike particles uniting together form one body without forming one substance, we have attraction of cohesion, and attraction of adhesion. These attractions may come from the influence of gravitation alone, or from chemical affinity acting by itself, but more commonly the result is brought about by the combined action of these two forces.

I have said that homogeneous elements do not attract one another chemically. It is a rule, however, which we have reason to think has certain exceptions. The tenacity with which the particles of some metals cling together—iron wire of a given thickness will support a much greater weight without breaking than a similar wire of any other metal—may be, perhaps, due to the internal structure of these substances, but it seems to point to a conclusion to which we are drawn by many facts which come before us in connection with magnetism, viz. that there exists between certain homogeneous elements, we cannot say chemical affinity, because that term is employed to signify the disposition which heterogeneous elements have to combine together, but at all events some kind of chemical or electrical attraction.

LECTURE VI.

THE NATURE OF ELECTRICITY (*continued*).

The theory of the chemical origin of electricity set forth—the process which takes place in the galvanic trough explained.

ACCORDING to this view the world of matter is not a dead inert mass. It is composed of parts which are instinct with powers of action and of motion, and which, besides being subject to the universal and uniform law of gravitation, are subject at the same time to the particular and diversified laws of chemical attraction. And just as sentient beings experience an endless variety of feelings, and these feelings, whether of pleasure or of pain, thrill through the body along the radii of the nervous system; so in material substances, devoid though they are of sense, there is, nevertheless a quick susceptibility of action, and a constant interchange of varying impulses, whenever bodies made of heterogeneous elements are brought together, either by actual contact or by means of the interposition of some insulated and conducting substance.*

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* All material substances are in a greater or less degree conducting. Those substances are good conductors which have homogeneous affinities throughout, and have their particles arranged in one

You are aware that the ancients spoke of matter as a Proteus having an aptitude, or, as they expressed it, an eager and restless desire to enter into new combinations of form. They held that, just as sentient beings have their different likings, so the particles of matter have their several affinities; and that, under every form or combination, whilst some of those affinities are spell-bound, there are others which remain free to contract any new alliance which occasion may offer. Modern philosophers, being better acquainted with chemical science, express themselves in a very different way, even where they do not differ in substance from the conclusions arrived at by the ancients. They tell us, for instance, that elementary substances arrange themselves in bodily form in accordance with the laws of chemical affinity. This self-arrangement or combination cannot, however, ordinarily take place unless one of the substances, if not both, be first brought to a fluid state, so as to allow the ultimate particles of the one substance to come into contact with those of the other. But when they have united together they are still ready to enter into new combinations. Take as an example potassium. This is a metal lighter than water. Being exposed to the air, it oxidises instantaneously, *i.e.* combines with oxygen. Being thrown

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uninterrupted line of contact. This is particularly the case with the metals and their alloys. Substances, on the other hand, are bad conductors which in their composition are made up of many heterogeneous elements, or in their construction are irregular and deficient in close contiguity of parts. To this class belong organic substances and elastic bodies. Faraday has established the fact that all gases have the same conducting power.

when fused upon water, it decomposes it, and, combining with the oxygen, burns with a purple flame. It readily combines with carbonic acid, forming with it the alkali potash, but it has a still stronger affinity for tartaric acid. If potash and tartaric acid be mixed in the dry powder, no alteration will take place. But if the potash be first dissolved in water, and tartaric acid be then added, the potassium immediately quits the carbonic acid; with which it formed potash, and unites with tartaric acid, forming with it cream-of-tartar. Thus we see in the case of this Protean substance, though it may have entered into one combination already, it has other latent affinities free to be acted upon. It is ready at any time to pass into new chemical combinations. So is it with all bodies. Whilst they have some of their affinities bound, they have others which are left more or less free. Now when these affinities are called into play without disturbing or altering the internal constitution of the body, the action may be said to be electrical; but when the existing internal constitution of the body is changed, the electrical becomes converted into chemical action. Sir Humphrey Davy, in a paper read by him before the Royal Society (*Phil. Trans.* 1826), says, " Chemical and electrical attraction is produced by the same cause acting in one case on particles, in the other on masses of matter. The same property, under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations."

This theory concerning the nature of electricity seems to me to be the true one. Electricity is that energy which is called forth when bodies having a mutual affinity are brought into communication either mediately or immediately. We have already seen how well this doctrine harmonises with facts connected with statical electricity. We now proceed to consider it in its application to current or voltaic electricity,* where the connection which exists between electrical and chemical action stands out much more clearly.

To explain the nature of current or voltaic electricity, we will take the case, not of a many-celled galvanic battery, but of a single galvanic pair. Let two plates, one of copper the other of amalgamated zinc, be placed in a vessel containing water, to which a small quantity of sulphuric acid has been added (Fig. 3¹). Whilst the plates are kept from touching they remain apparently unaffected. If, however, they be made to touch, a current of electricity is at once established, bubbles of hydrogen gas are formed in abundance at the copper plate, and their formation continues as long as the plates remain in contact. If the contact be maintained for some time, and the plates and liquid be then examined, it will be found that the copper plate weighs exactly the same as before, that the zinc plate has lost in weight, and that the liquid contains the lost zinc in solution in the form of sulphate of zinc. The contact need not be effected by the plates themselves. If iron or copper wires be soldered to the plates, and be made to touch, the same changes will take place as if the plates themselves were united together.

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* By current electricity is understood the electric action which passes along a conductor, from the source where it is originated, to the reservoir where it is absorbed. By statical electricity is meant that which is accumulated or concentrated on the insulated surface of a body charged with electricity. It is sometimes called frictional electricity, because it is for the most part derived from friction.

I have said, so long as the plates immersed in the liquid are not brought into contact no apparent change takes place. It will be found, however, upon examination, that the plates are not absolutely unaffected. The free end of the zinc plate shows signs of negative, the free end of the copper plate shows signs of positive electricity; but immediately the plates are united there follows a rapid decomposition on the surface of the zinc, the liberation of hydrogen at the copper plate, and the development of an electric current between the two plates. If a magnetic needle be suspended above the liquid, and over the wire which connects the two plates, it will be found that a current flows in the trough from the zinc to the copper plate, and out of the trough completes the circuit from the copper to the zinc plate. How are these different effects, which take place before and after the junction of the plates, to be accounted for?

Before entering upon the explanation of the process which takes place in the galvanic trough, let me first observe that the liquid possesses that amount of cohesion amongst its parts which enables it to act as a whole. Being inclosed in a tube or cylinder where there is no outlet, it transmits from one end to the other any mechanical pressure to which it is subjected. In like manner, being put in a vessel or trough which is insulated, it is capable of transmitting from one part to another the action of any electrical force which is communicated to it. Let me also recall your attention to a fact which has already been noticed, that when, out of the elements brought together having a mutual affinity, one is in a liquid state, they more easily act upon one another. We have here then two plates, the zinc and the copper. Both have an affinity for the oxygen element of the water in which they are immersed, and have also an affinity for each other, the zinc being electro-positive in relation to the copper. Under these circumstances we should naturally look for some electrical or chemical effect to take place. First let us consider the action of the two plates, one upon the other, before the circuit is completed. The oxygen element of the water being negative, the hydrogen positive in relation to the zinc, the zinc acts upon these two elements of the water in the same way in which we have seen the excited zinc of the charged brass ball acts upon the negative elements of the brass cylinder. It attracts the negative (oxygen) to itself, and it makes use of the positive (hydrogen) as a conductor by which it transmits its influence to the copper plate, which it throws into a negative state on the side turned towards itself. But, the copper being a conducting substance, the zinc will act through it upon those objects for which it has an affinity which lie beyond, so that the farther end, or outside face, of the copper plate will show signs of positive electricity. In like manner the copper, which has an affinity for the zinc and is negative in its regard, will act through the hydrogen element of the water, and throw the zinc on the side turned towards it into the positive state. The zinc being a conductor, the copper will act through the zinc upon those elements for which it has an affinity which lie beyond, and thus the outside face of the zinc plate will show signs of negative electricity. Next let us consider the action between the plates and the liquid when the circuit is not yet completed. The action of the oxygen element of the water upon the zinc is similar in kind to that of the copper plate, although greater in degree. It will excite positively the face of the zinc plate which it touches, and, acting through the conducting zinc plate, will throw the other side of it into a negative state. But why does not the oxygen chemically combine with the zinc? The answer, I think, is that the attraction of the oxygen for the zinc is neutralised in great part by its attraction to the copper. A plate of zinc immersed in water slowly oxidises; but when a plate of zinc and a plate of copper are both together put into water in an insulated vessel, no oxidation takes place so long as the two plates remain separate, because both plates attract the oxygen different ways. So much for the effects which are produced before the two plates are united. The free end of the zinc plate shows negative, the free end of the copper plate positive electricity.

When the two plates immersed in the water are united together there is, in the first place, a complete circuit formed so as to allow of the continuous flow of whatever electricity may be generated by the action of the liquid upon the metals. In the next place, the two plates being now united together, and forming electrically one body, must act as one body. Either then the zinc must act directly upon the oxygen element of the water, and the copper act upon it through the zinc, or the reverse of this must take place. But the zinc has a stronger affinity for the oxygen than the copper has; for this reason the zinc acts upon the liquid immediately, the copper acts through the medium of the zinc. The copper has, it is admitted, an attraction to the liquid in contact with it, but it has a stronger attraction the other way; otherwise there would not be that complete circuit of an electric current—flowing in the liquid from the zinc to the copper plate, and out of the liquid from the copper to the zinc plate—the existence of which is proved by the magnetic needle. The copper is in fact attracted in this direction both to the zinc, with which it is now brought into immediate contact, and to the oxygen element of the liquid upon the surface of the zinc, with which it is brought electrically into contact through the medium of the zinc plate; so that whatever electro-motive power is now exerted by the copper upon the oxygen element of the water is exerted by it in conjunction with the zinc, and the liquid decomposes upon the surface of the zinc plate.

This decomposition of the liquid taking place on the surface of the zinc plate, why, it may be asked, does not the hydrogen element, for which neither the zinc nor the copper possesses any affinity, escape at once when it is set free into the air, instead of ascending into it at the opposite side of the trough from the surface of the copper plate? The reason of this appears to be the following:—There is a double action going on here. The oxygen and hydrogen elements of the liquid are attracted in opposite ways. This is the cause why the decomposition of the liquid takes place so rapidly. When a piece of iron is thrown into a vessel of water it rusts—or, in other words, it oxidises—slowly. Whereas, if it be kept wet in the open-air, it rusts much more quickly, because in the latter case the hydrogen element of the water is attracted by the free oxygen in the atmosphere, at the same time that the oxygen element of the water is acted upon by the iron, and consequently the decomposition of the liquid is effected more easily. Now something of a similar kind happens in the case before us. The oxygen element of the liquid being attracted to the zinc plate by reason of the mutual affinity they have one to the other, and the hydrogen element being attracted to the copper plate—not from any affinity which it has to the copper, but from its affinity to the oxygen with which it is brought into connection through the medium of this conducting metal—the rapid decomposition of the liquid ensues; a molecule of oxygen being continually disengaged on the surface of the zinc plate, and entering into combination with the zinc so as to form an oxide of that metal, and a molecule of hydrogen being at the same time liberated on the surface of the copper plate, which being unable to unite chemically with the copper transmits an electric shock along the conducting metal, and ascends into the air. But admitting this, how, it may still be asked, are we able to explain the fact that when the molecule of water is decomposed upon the surface of the zinc plate, and the oxygen element enters into combination with the metal, the hydrogen element vanishes from the place where it is set free and makes its appearance at the other side of the trough, where it rises into the air? The only possible explanation of this phenomenon seems to be that of Grotthus, viz. that, in consequence of a negative electric current passing from the copper to the zinc, and a positive electric current passing from the zinc to the copper—in other words, in consequence of the oxygen element of the water being everywhere in the vessel attracted to the zinc plate, and the hydrogen element of the water being attracted to the copper plate—the hydrogen set free on the surface of the zinc combines with the oxygen element of the molecule of water next to it in the direction of the copper plate. In like manner the hydrogen element of this second molecule of water combines with the oxygen element of the third molecule of water in the same direction, and so on through the liquid. Thus there is an uninterrupted series of decompositions and recombinations going on between the two plates, whereby, as we have seen, on the one side a molecule of oxygen is continually disengaged, which combines with the zinc, and on the other side a molecule of hydrogen is continually set free, which, not being able to combine with the copper, escapes into the air.

There are some points here which require further explanation. First, it must be understood that a real transfer of elements takes place in the transformations effected by the force of chemical attraction. In proof of this I may refer to an interesting experiment of Sir H. Davy (Fig. 12). He arranged three glasses, putting into the first pure water, into the second a weak solution of ammonia, into the third a solution of sulphate of potash; and connected the glasses together by pieces of amianthus. He then made a strong electric current pass from the first glass through the other two in succession. In less than five minutes a piece of litmus paper which inclosed the point of the positive electrode showed signs of the presence of the acid, which, after undergoing various transformations, had made its way from the third glass through the second, containing a solution of ammonia, into the first, which was filled with water. In the case before us, the transformations which take place being of the simplest kind are accomplished with wonderful rapidity.

Next let me endeavour to show more clearly that the decomposition of the liquid on the surface of the two plates is due to chemical attraction. Between the oxygen element of the water and the zinc plate there is chemical action. This all will admit. In like manner the decomposition of the water on the surface of the copper plate seems due to the same cause. The oxygen and hydrogen elements combined together in the water are both alike acted upon, and are drawn in opposite directions. The former is drawn away from the copper plate to unite itself to the hydrogen element, which is in a nascent state, having just been displaced in the contiguous molecule of water; the latter is drawn to the copper plate, not from any affinity it has to the copper, but because through this conducting medium it is brought into contact with the oxygen element on the surface of the zinc plate. For if the electric flame passing through a vacuum tube is at once drawn to the side by approaching the hand to it, and if the electricity contained in the charged Leyden jar acts through so bad a conductor as glass upon any body in contact with the external surface of the vessel, we cannot doubt that hydrogen and oxygen in an excited state must exert a powerful attraction upon one another when acting through so good a conductor as a metallic medium.

But to establish the fact that current electricity is nothing else but chemical action in another form, it is of importance that the point we have been considering be put in the clearest light. I will therefore illustrate what I have said by referring to the process of the decomposition of water by means of the galvanic battery. Let two wires, having slips of platinum soldered to them, be made to pass into a vessel filled with acidulated water. The reason why the wires have slips of platinum attached to them is because this metal does not enter into combination with either oxygen or hydrogen, of which water is formed, so that both are disengaged. Over the ends of the platinum let there be two glass tubes suspended to receive the gases when evolved. As soon as the conducting wires are put in connection with the galvanic battery, decomposition of the water ensues.

Oxygen is evolved at the positive, hydrogen at the negative electrode, and between the two terminals a succession of chemical changes takes place in the liquid. Twice as much hydrogen is evolved as oxygen, this being the proportion in which the gases unite together in the formation of water. What is it, it may be asked, attracts the oxygen to the one electrode, the hydrogen to the other, thereby producing that series of transformations which takes place in the liquid? Not any affinity which they have to the platinum—which, if any does exist, is too slight to be able to dissolve their union one with the other—but the affinity they have to the elements in the generating cell of the battery with which the conducting platinum wire places them in communication. Hence we find the oxygen of the water attracted to that wire which is in conducting communication with the hydrogen or positive element of the generating cell, and the hydrogen of the water attracted to the wire which is in connection with the oxygen or negative element of the galvanic trough. Other examples might be given. Thus, *e.g.*, if a current be sent through a solution of common salt or a solution of the iodide of potassium, the metallic sodium and potassium are attracted to the wire which connects them with the oxygen, the non-metallic chlorine and iodine are attracted to the wire connecting them with the hydrogen, for which they have an affinity. If, however, we substitute mercury or some other fused metal in place of the water or other solution, the electric current would still continue to flow, because the liquid metal is a conductor of electricity; but no displacement would take place: and why? In the former case decomposition of the water or other solution took place because its constituents were, as we said, drawn in opposite directions, the one having an affinity to the hydrogen, the other to the oxygen element of the generating cell, and each being furnished with the opportunity of obeying the impulse by which it is stirred. But in the latter case all the particles are alike in their affinities, so that on this ground there is no tendency amongst them to displace one another; and all the particles being alike in their conducting capacity, as well as in their nature, they will all serve alike to transmit the positive and negative currents which pass between the two terminals; and, since these currents are equal in force, they will not be drawn by them more powerfully in one direction than in the other.

From this we may see the answer which is to be given to an objection that might be drawn from the alleged fact that no element or substance can be transferred or pass from pole to pole, unless it be in chemical relation to some other element or substance tending to pass in the opposite direction, the effect being essentially due to the mutual relation of such particles. Thus pulverised charcoal, or sublimed sulphur, diffused through dilute sulphuric acid, exhibits no tendency to pass to either pole. Yet in these cases the attraction of cohesion is almost perfectly overcome, the particles are so small as to remain for hours in suspension, and are perfectly free to move by the slightest impulse towards either pole.*

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* Noad's "Student's Textbook of Electricity," p. 210.

Why then, it may be asked, are not, *e.g.*, the charcoal particles carried to the negative electrode by the affinity they have to the oxygen element of the generating cell?

In proof of the statement that no element can pass from one pole to the other unless it is in chemical combination with another element tending to pass in the opposite direction, we have the example quoted of the decomposition of chloride of silver by silver electrodes. If we fuse a portion of chloride of silver upon a piece of glass, and then bring the two poles in contact with it, silver will be evolved at the negative and in the same degree absorbed at the positive electrode. No chlorine is set free. By careful management the negative wire may be drawn away from the globules of silver which have been deposited, so that, the globules themselves serving as a continuation of the pole, a wire or thread of revived silver will be produced. It is necessary, however, in this case, that the positive electrode be gradually advanced, in order that the chlorine may have matter to act upon for the continuance of the process of the absorption and transfer of the metal.* In like manner, we are told in another place that if charcoal be made the negative electrode in a metallic solution it refuses to unite to the bodies which are ejected from the solution on its surface; but that if it is made the positive electrode in dilute sulphuric acid it is capable of combining with the oxygen evolved there, and consequently unites with it, producing both carbonic acid and carbonic oxide.† The

* Ibid. p. 211. † Ibid. p. 215.

reason why the charcoal refuses to combine in the former and combines in the latter case seems to be this, that in the former case the element which is deposited upon it is not the oxygen or chlorine, or other electro-negative element for which it has an affinity, but some metallic substance for which it has none; whereas in the latter case it is the oxygen or the sulphuric acid for which it has a strong affinity.

Let us proceed now to consider why the charcoal powder diffused through the sulphuric acid, through which an electric current is made to flow, shows no tendency to pass to either pole. Being at a certain distance from either pole, if the charcoal particles are carried to the negative electrode—which is that to which we might expect they would be drawn—they must be carried thither either by the force of current or by the force of statical electricity; in other words, they must enter into combination with one of the elements of the liquid, and so, passing through a series of transformations, be transported to the negative pole; or they must be borne along, by the electric charge which they have received, in the direction of the pole which is of the opposite electric character.

Pure carbon is capable, as we have seen by the last example brought forward, of combining with the elements of dilute sulphuric acid, and of being thus transported to the negative pole; but it is not capable of this under the circumstances of the case before us. The particles of charcoal are neither in a heated nor a nascent state, when they more readily combine with other substances. Moreover, though they have an affinity to the oxygen of the decomposed liquid, they have not so strong an affinity as the hydrogen and sulphur, which are in a nascent state. They remain therefore in the liquid in an uncombined state. But a substance which is charged with either positive or negative electricity will, if it be free to move and cannot easily part with its electrical burthen, be carried to any neighbouring body which is in an opposite electrical state. Thus a pith ball which has received a positive charge, if it be suspended between two balls, the one positively, the other negatively electrified, will be drawn to that ball which is negatively electrified; and, when now it has received a negative charge, it will be attracted to the ball which is positively electrified. It cannot, however, be said that the particles of charcoal which are suspended in the liquid between the two poles are either positively or negatively charged. They have two currents of equal strength passing over them, and they are conductors of electricity, but they can be compared to nothing else but to an insulated cylinder, which being placed between two oppositely electrified bodies, and having positive and negative electricity accumulated on its opposite ends, is drawn with equal force in two opposite directions. It remains stationary. And so the particles of charcoal, being attracted with equal force to the two poles, remain in the same position.

Another point may seem to require a few words of explanation. The process represented as taking place in the galvanic trough supposes a series of transformations going on uninterruptedly through the liquid. It supposes two currents proceeding in opposite directions, the oxygen element of the water being drawn towards the zinc, the hydrogen element towards the copper plate. Must we admit the passage of an electric current between the zinc and the copper as distinct from the chemical action which produces these transformations? No doubt this current exists before these transformations begin to take place, and whilst they are taking place there may be some elements in the liquid which are not affected by these transformations and would remain under the influence of it still; but if we regard electrical and chemical action as essentially one and the same, there seems no reason why we should suppose the same particles to be at the same time under the influence of both. The presence of either one or the other is sufficient to account for the effect produced upon the magnetic needle, and the rapidity with which chemical changes pass through the liquid is scarcely less than that which characterises the passage of an electric current. It is true, undoubtedly, that the conducting power of a solid body which does not go through these transmutations is superior to that of any fluid which is subject to them, but we may judge how quickly these transformations may take place through a liquid under favourable circumstances from what takes place in a connected chain of solid bodies, as, for instance, when a train of gunpowder is fired. The explosion runs from particle to particle along the line of powder, yet, whatever its length may be, it is traversed in a few seconds. Yet what is this explosion but a series of chemical decompositions, and of recombinations under a different form, of the elements of which the gunpowder is composed?

The transfórmations effected in the galvanic trough take place with greater rapidity because they are of a simple nature, and the forces in operation act simultaneously at either end, so that at almost one and the same time an atom of oxygen enters into a new combination on the surface of the zinc plate, and an atom of hydrogen is disengaged on the surface of the copper plate, all the intermediate atoms of oxygen and hydrogen separating from one another and then uniting with their adjacent particles. When, however, an electric spark is transmitted by an electric machine through a vessel of water, decomposition is effected with a greater degree of violence, the constituent elements of the liquid being parted asunder too widely along the passage of the current to allow of any reunion of the separated particles being brought about by the attraction of their affinities one to another. In the experiment of Sir H. Davy to which I referred a short time ago, an interval of a few minutes elapses before there is any indication of the transfer of any of the elements contained in the third glass through the second into the first; but it is doubted, in this case, whether the process of transformation begins before a connection between the three vessels has been established by capillary attractions across the syphons.

I will here address myself to a point bearing upon the explanation given of the decompositions effected in the galvanic cell which I have not had an opportunity of noticing before. How is it that the platinum wires in the decomposing cell exert an attraction so powerful upon the constituent gases of the water as to dissolve their union, and yet are not able to retain their hold upon them and prevent their passing at once into the air or into the vessels put to intercept their passage; whilst a bit of sealing-wax rubbed with a silk handkerchief makes the light objects adhere to it which its feeble electricity is capable of attracting? The reason of this is that the attractive force generated in the galvanic trough, and acting through the platinum electrodes, is an intermittent force. The oxygen element of the liquid, acting upon the surface of the zinc plate, exerts a powerful attractive force, which is transmitted by the conducting wire, but when it unites in chemical combination with the zinc all electric action ceases for the moment, until a new oxygen atom takes the place of the former. The interval may be of the shortest duration possible, but in the mean time the hydrogen element in the decomposing cell is liberated from the platinum wire, to which it has of itself no affinity, and by its own specific lightness is at once carried into the air. The more rapid the chemical change which goes on in the galvanic trough, the quicker will be the succession of electric shocks transmitted by the conducting wire and the evolution of the gases in the decomposing cell.

There remains yet one point more upon which it is necessary to say a few words. For the sake of simplicity I have spoken of the transformations taking place in the liquid as if it contained only the elements of oxygen and hydrogen, but you will remember that I supposed a small quantity of sulphuric acid to be mixed with it: why was this? If pure water were used, the oxygen element would gradually form an oxide upon the surface of the zinc, like a coating of rust upon iron, which would protect the metal from all further action of the liquid; and, chemical action ceasing, there would be a cessation of the electric current which is generated by it. But if acidulated water be used, the oxygen is no sooner deposited upon the surface of the zinc, with which it combines, than it is taken up by the sulphur, and forms a sulphate of zinc which is held in solution in the water, leaving the face of the metal as clean as before, to recommence its action upon the liquid. Some explain this a little differently. Looking upon the sulphur as the more active chemical agent, they suppose it to combine with the zinc, for which it has a strong affinity, and, as soon as it is deposited upon its surface, to be taken up immediately by the oxygen of the water, the quantity of which should exceed considerably that of the sulphuric acid. Whichever of the two views be adopted, the conclusions which follow will be the same as regards the attraction of the oxygen and sulphur to the zinc plate, and the attraction of hydrogen to the copper plate, and as regards the consequent transformations which pass through the liquid, and the transmission of electric action along the conducting wire.

If the explanation which has been given of the process which takes place in the galvanic trough be a correct one, there can be no doubt about the close connection which exists between the chemical and electrical powers. The one acts in the voltaic circuit upon the conducting wire, the other acts in the generating and decomposing cell. And it is not enough to say that they aid and assist each other in their operation: the action of the one merges into that of the other; they are the same in character and differ only in degree.

We have then, it appears to me, good reason for concluding that electricity is not a real fluid, nor a material substance at all, but a power or force residing in matter. I shall have occasion hereafter to add more in the way of proof bearing upon the same subject, but we may address ourselves now to the consideration of a new question, viz., admitting electricity to be in reality a force, what are the nature and properties of electric force?

LECTURE VII.

ELECTRICITY A FORCE INHERENT IN MATTER.

Those who recognise electricity as an immaterial agent are at issue upon the question whether it should be regarded as a force extraneous to matter or inherent in it—The latter hypothesis more consistent with what we know of other physical forces, and with what we know of this

IT being admitted that electricity is not a substance, but a force, the next question that arises is, What is the nature of that force? Upon this point there are two opinions. Some hold that electricity is a force or energy developed in matter; others maintain, and their opinion is perhaps the more common one, that it is a force which is propagated through matter, but in its nature separable from and independent of it. There are consequently two different ways in which the transmission of this force is explained. Some suppose a similar force to be developed successively in each of the contiguous particles of the conducting wire, just as in the series of chemical transformations which takes place in the liquid a new transformation takes place at every step up to the last, when an atom of hydrogen is extruded upon the surface of the copper plate; whilst others hold that the same identical force which is generated in the galvanic trough by the decomposition there effected manifests itself subsequently in another place and under another form. I have said this last opinion is very generally held at the present day. It is in accordance with the doctrine which affirms that the force of the blow upon the anvil is converted into heat; that the energy of the railway carriages in motion, when they are suddenly stopped, is converted into the sparks of fire which are emitted by the break-wheel which arrests the motion of the train. One might, it would seem to me, with equal reason assert that the energy of two trains coming into collision together is converted into the broken arms and legs of the passengers, the abrasion of the metal and the fracture of bones being, the one just as much as the other, an effect produced by that energy. Before passing, however, to the proof that electricity is not a force altogether distinct and separable from matter, but one which is developed in it, it may be well that I should make some preliminary observations.

Many persons take it for granted that there are in the world physical powers separable from matter. Hence they are easily brought to look upon so mysterious an agent as electricity as belonging to this category, the more so because the marvellous velocity of its motion may thus, they think, be more readily accounted for. Now I do not controvert the doctrine that there is in the world a fixed quantity of force, just as there is in the world a fixed quantity of matter, and that it is no more in our power to create the one than the other, all, in effect, that we can do in regard to material forces being to modify the form which they shall assume, and to determine the direction in which they shall be made to act. But as to the forces themselves which we find in nature, they are all of them, as it seems to me, modifications of three distinct and independent powers, which three distinct powers are inherent in every particle of matter. The first is that general attraction which every atom has to every other atom. This we call the attraction of gravity. The second is that special attraction which each atom has to certain other particular atoms, and which it has not to all atoms alike. This we call the attraction of affinity, or chemical attraction. The third is the force of inertia. Now these three forces exist in all material particles, and we can neither diminish nor take them away. It is true we may combine together, *e.g.*, oxygen and hydrogen so as to form water, and it might perhaps at first seem as though we had thereby taken away some of the chemical forces belonging to these gases in their primary state. But it is not so; for, as soon as we again decompose the water into its constituent elements, it is found that they possess the same forces they had before. The same elements, it is true, exhibit different properties in composition and out of it; but the reason of this is that in composition some of the forces of these elements are absorbed by their internal action one upon another, and those which remain unbound and are capable of acting externally—by which alone we judge of the nature and constitution of any body—give consequently a different result. It may even happen that the very same elements combined together in the very same proportions may yield products as widely differing from one another as, *e.g.*, cane-sugar and gum-arabic. No doubt, in cases of this kind, though the elements which are combined and the porportion in which they are combined are the same, the order in which they enter into combination is different, and leads to a different result. Neither do I deny that bodies may pass out of one state into another in which they will exhibit different properties. Thus water may be converted into steam as well as into its constituent gases. Thus the food we take, being chemically acted upon by the gastric juice, is converted into chyle, and chyle is converted into blood, out of which many different substances are formed. But these are examples of a body undergoing change, not from any force belonging to another body being transfused into it, but by the force of another body acting upon it; or else by the fact of another body, with its own array of forces, combining with it. It is only in one way, as it appears to me, that the forces belonging to one body impress themselves upon another, viz. as causes producing their effect. Thus the force of the fire in the furnace of the engine—or, in other words, the molecular motion generated by combustion amongst the particles of the fuel—does not pass through the boiler into the water which it contains, but it acts upon the boiler, and if the boiler be not kept full of water it burns it away. In the same manner the boiler thus acted upon acts in its turn upon the water which it contains, which is converted into steam—the expansive power of the steam being regulated by mechanical contrivances so as to propel the engine. The motion of the carriage on the line produces friction, and friction produces heat. Thus from the beginning to the end the relation which each step in the series has to that which follows is one of cause and effect. Now between the transmission of motive power and of electric force there is a close analogy. The force of the moving train is not converted into, but produces the molecular motion of heat; so the force of the electric current is not itself converted into, but produces heat in the conducting wire; and in like manner all the other effects which we ascribe to the action of electricity. These remarks may be thought, perhaps, to betray a certain amount of simplicity on my part. Certainly I do not quarrel with any one who speaks of the momentum of the train being converted into the sparks of fire emitted by the break-wheel, provided it be understood that this form of expression is not intended to convey a scientific explanation of the fact which takes place. All that I wish is that the distinction which I have dwelt upon be taken into account when we are considering what is the true nature of electric force.

I need only notice, *en passant*, that this theory of the transfer of certain forces from one body to another goes beyond the doctrine, philosophically considered, of transubstantiation, which teaches that, by miraculous power only, the accidents or external forces belonging to a substance may remain after the substance to which they did belong has passed away and given place to another. I cannot, however, omit to call attention to the fact that, if, without any miraculous intervention, the external forces of bodies may pass from one to another, we are left without any certain means of knowing what any substance is, or what change of one substance for another may not at any time take place. It is no answer to say that heterogeneous substances differ primarily not in their external forces, but in their internal properties, because we have no means of judging what their internal properties, what their hidden nature is, except by the qualities they manifest externally.

It may be said, perhaps, that all external forces are not alike, that some external forces are indissolubly bound up with the internal forces of bodies, so that a change in the one would involve a change in the other; but that it is not so in regard to others, and that all that is meant is, that those forces which do not belong essentially to bodies may be transferred from one to another. Thus mechanical force, for instance, being a power which belongs only accidentally to the body in which it is found, may pass out of that body into another. Now I am willing to admit of a distinction being made between those properties and powers which belong to a body essentially, and those which belong to it only accidentally. But I see no ground for the assertion that there is between the properties or powers belonging to bodies a further distinction of this kind, viz. that whereas some of them have only a parasitical life dependent upon the existence of the subject in which they inhere, others on the contrary have a distinct and separate existence, so as to be capable of passing out of one body into another. This has never been proved to be the case, and the instance brought forward—and no better instance could be chosen—does not warrant such an assumption. Mechanical force does not differ in its origin from other material forces, neither will it be found to differ in its mode of action. The force of the stream turning the wheel of the mill grinds the corn. Whence does the stream derive this power? The attraction of gravitation first sets the water in motion, and continues to act upon it throughout its course. The property of inertia—which, like the force of gravity, is inherent in matter, and by virtue of which matter continues in the same state in which it has once been placed, whether of motion or of rest, until a change in that state is brought about by some external agency—this property of *inertia* is a second cause which operates in conjunction with the first in maintaining the onward movement of the stream. And how does the force of the current produce the revolution of the wheel? According to the theory I am speaking of, the force of the current passes from the running water into the wheel which the water turns. We have seen that the movement of the stream is caused by the combined action of the force of gravity and of inertia. It is not, of course, meant that these natural forces of matter pass out of the water; but what I suppose is meant is, that the momentum which the water has acquired from the foregoing action of these natural forces—which is a mechanical power—is thus transferred. But does this doctrine accord with the teaching of experience. Let us suppose that two leaden balls, A and B, of the same size, and moving with equal velocity from two opposite quarters, come into collision together. If the mechanical force which carries forward A (which mechanical force is in reality nothing else but the action of the force of inertia) pass out of A into B, and the force which propels B pass out of B into A, the two balls ought, after coming into collision, to be carried back with the same velocity to the places from which they came. Does this result take place? What really does take place shows that the force in each of the two balls does not pass out of the one into the other, but has the effect in each one of neutralising the propelling force in the other. The movement of the two balls in their onward course is arrested, and the force of gravitation, which still continues to act upon them, makes them fall to the ground. It may be admitted that the mechanical force which acted upon the two balls has not been absolutely destroyed. It continues in one sense to exist in the effect produced by it. By the collision which has taken place between the two balls, and by the agitation produced amongst their ultimate particles which has been the consequence of that collision, a certain amount of heat has been generated. Heat, however, is admitted to be a species of mechanical motion, and what I have said concerning mechanical force in general I say also concerning heat. It is not a force which goes out of one body into another, but it acts as a cause producing in bodies which come under its influence a state similar to its own. Neither heat, nor mechanical force, nor any other force that I am aware of, can be adduced as an instance of powers which are in their nature distinct and separate from the material substances in which they are found, and are capable therefore of being transferred from one body to another.

These few remarks will suffice upon this subject. I may be thought perhaps to have gone out of my way to speak upon it at all; but as there are many who, taking the existence of a certain number of independent forces in nature for granted, are disposed to look upon electricity as belonging to this category, I have considered it of importance to show that, as far as our knowledge goes, there is no evidence for the existence of any such class of forces, or indeed for the existence of any one force of this kind. And as regards electricity we shall find there is nothing in the facts connected with it which would lead us to suppose that it differs in this respect from other forces.

At the present day almost all agree that the source of electricity is chemical action—chemical action in one form or another, developed in a greater or less degree. No great electric force can be generated, no strong current can be set in motion without chemical action in its highest form. In the galvanic battery the electric current has its origin in the decompositions which there take place, and any increase of intensity in the action which goes on in the decomposing cell is always accompanied by a corresponding increase in the force of the current which passes along the conducting wire. It must, however, I contend, be admitted that, in a less degree, electricity may be developed where no chemical change that is perceptible takes place, but where bodies having mutual affinities are made to act one upon another. You have already had abundant proof of this in the case of electric induction, if my explanation of the manner in which the charged ball acts upon the insulated cylinder and the pith ball be correct. But not only does electricity owe its origin to chemical action, excited in a greater or less degree: for every stage in its progress it is indebted to the same cause. Were electricity a disembodied force (I have contended that we have no example of any such force existing in the material world) we might expect that it would pass without hindrance from one terminal to the other in a vacuum tube. Now it is true we cannot obtain a perfect vacuum, and point to the fact that in this case absolutely no electricity will pass through it, but we may obtain a vacuum so perfect that electricity will not be able to pass without great difficulty. Again, were electricity a force which depended for its transmission, not upon the chemical affinities of the conducting medium, but only upon the chemical affinities of the elements brought into connection with one another by that medium, we might expect that it would act just as readily and as powerfully through one conductor as through another, provided only the particles of the one and of the other stood in the same unbroken contiguity. But this is not the case. A good conductor must in the first place be homogeneous in its chemical affinities through its whole length. The particles of a metallic rod or wire have this uniform character. A good conductor must in the second place be homogeneous in its affinities with one, heterogeneous with the other of the diverse elements which it brings into connection. Thus the copper-wire conductor has homogeneous affinities with the hydrogen element on the one side, and chemical affinities with the oxygen element on the other side. Furthermore, it is necessary that the external particles of the conductor should be free from any other disturbing chemical action. These conditions all point to the fact that electricity is dependent for its transmission, no less than for its origin, on chemical agency, and that the electric current is nothing more than chemical action communicating itself from one particle to another along the whole line of the conducting wire. I will bring forward a certain number of examples in corroboration of these several statements.

First, between the links of an iron chain interpose a few links of ebony or ivory, or any other substance which has no chemical affinity to the metal, at once the passage of the electric fluid is stopped. Next let an iron-wire conductor be in one part reduced to one-half its thickness. Since the fewer number of particles contained in the surface of the thinner wire has now to do as much work in transmitting electric pulsations as the greater number of particles contained in the surface of the thicker wire, these fewer particles receive an accelerated motion. Growing red-hot, they are acted upon chemically by the oxygen in the air. Whilst their affinities are thus in part fettered and bound, they cease to afford the same facilities for the passage of electricity. If the conducting wire be cooled, it recovers its power. In the diminished conductivity of the telegraph wires in foggy weather we have another illustration of the same fact. How is this effect produced? The globules of the mist resting upon the iron wire, the oxygen of the decomposed globule separates from the hydrogen, and combines with the external particles of the iron wire, coating it with rust. Whilst this chemical action is at work upon the surface of the wire its affinities are to a certain extent spell-bound, and it no longer offers a ready pathway for the transmission of the electric fluid. In accordance with this explanation of the fact, we find that if the iron wire be galvanised, and so rendered impervious to the action of the oxygen of the mist, it does not lose its conducting power. Again, we find that if an iron wire be carried through a tube charged with hydrogen gas, it does not lose its conducting power to the same extent as when made to pass through a tube filled with oxygen gas—the latter gas having a chemical affinity to the iron which the former has not. Lastly, when the wire is divided into two parts, so that they no longer touch one another, the current will cease to flow. But if the two ends of the wire thus divided be made to dip into a vessel containing diluted sulphuric acid, or any other liquid having an affinity to the metal, the electric current will once more be set in motion (Fig. 3^1). Thus electricity is found to maintain chemical action in a greater or less degree throughout its entire course.

LECTURE VIII.

THE SAME SUBJECT CONTINUED.

The electric light—The electric spark—The stratified light of the induction coil—Lightning and thunder.

THE proof that electricity is not a force which exists independently of matter, but one which is developed in it, will be complete if it be shown that electricity not only takes its rise in the action of those affinities which bodies have one to another, and is indebted for its continuance and transmission to the same cause, but ends also as it begins in chemical change. For if there be anything which we regard as inseparably connected with matter, it is surely the affinities and properties which belong to its primary elements, upon the mutual action of which upon one another all chemical combinations depend.

My first example of the conversion of electrical into chemical action will be taken from current electricity. Let the ends of two wires which proceed from a powerful galvanic battery, and are furnished with carbon points for their poles—a substance rivalling the metals in their conducting power but less fusible—be first brought into contact so as to establish an electric connection between them, and then separated from each other a short distance only, so that the electric action can still be maintained through the intermediate stratum of air, we have then the electric light produced, the nearest approach we can make to the brilliancy of the sun. The fine tapered pencils of charcoal become so intensely heated by the powerful action of the battery concentrated upon them, that when they are drawn asunder particles of the carbon fly off from one pole to the other, being in part transferred in an incandescent state and in part volatilised and consumed in the oxygen of the air. If any metallic substance, *e.g.* sodium, be inserted in one of the cones of the charcoal pencils, it is vaporised, and becomes incandescent, imparting a brilliant hue to the intervening arc of flame. Now, when we come to fire, we have surely passed the boundary-line which divides electrical from chemical operations and effects, and are dealing with a substance which has been decomposed into its primary constituents, and is re-entering, in a gaseous form, into some new combination.

Statical electricity furnishes us with a very common yet apt illustration of the conversion of electrical into chemical action. Upon turning the electric machine the ball in connection with the prime conductor will have its affinities raised to a high degree of tension, and being brought near to a body in an opposite electric state will emit a spark. The analysis of the light of this spark gives us the spectrum of the material of the electrode from which it passes, superimposed upon the spectrum of the gases of the air kindled into an explosive flame.

You may ask, how does it come to pass that the substance of the conductor should become so soon vaporised, when we have no great amount of heat developed? The answer is that the rays of greatest chemical power are not those of greatest heat, but lie on the opposite side of the spectrum. The electric current transmits chemical energy. It develops heat only so far as the action of its chemical affinities meets with resistance. I may here notice that the spark which proceeds from the positive pole or electrode through the the air is, as a rule, more brilliant than that which proceeds from the negative one. The reason of this is that the oxygen element of the air is drawn to the positive electrode, the nitrogen element to the negative; and, of the two, the oxygen is a better supporter of flame.

When the discharge is made to pass through a glass tube by means of wires hermetically sealed into its ends, many interesting phenomena are displayed, some of which I will take notice of briefly. When the glass tube through which the sparks are sent is filled with air, red vapours begin after a short time to appear, proving that oxygen and nitrogen have entered into chemical combination. On the other hand, when sparks are sent through a compound gas, such as ammonia or aqueous vapour, it is gradually decomposed. In condensed air the spark is short and compact; in rarefied air or gas it receives a wonderful development, but is less intense in light. When the discharge passes through the tube directly from the battery, or from the electric machine, the light which it generates appears to be continuous; but when the discharge proceeds from an induction coil the light is found to be not continuous but stratified (Fig. 9). Scientific men differ from one another in the way in which they account for this phenomenon. Grove, who was the first to observe it, looks upon it as the result of a conflict of currents in the rarefied medium, which he explains in this manner:—When the battery contact is broken, there arises in the secondary wire an induced current flowing in the direction in which the interrupted battery current flowed before. It is to this secondary current that the brilliant effects of the coil are to be attributed. But besides this induced current in the secondary wire, there is also an extra current developed in the primary by the battery current, as shown by the spark which follows the interruption of the battery current. This extra current in the primary produces a counter current in the secondary. Thus we have in the secondary two currents flowing simultaneously in opposite directions, and, by the conflict or irregular action which they cause in the rarefied medium, giving rise to the stratified appearance which is seen in the tube. Gassiot, who has studied this whole subject very closely, holds a different opinion. He considers the stratifications in the vacuum tube to be the result of a force acting in a series of pulsations or vibrations upon a highly attenuated medium. But since the action of electricity is always of the same nature, it would follow therefore that the electric light in the vacuum tube consists always of a succession of luminous and dark bands, although it is not under ordinary circumstances, but only when the velocity of its passage is reduced, that we can discern its real character. It has been ascertained by Gassiot that, provided the intensity of the current be reduced by the introduction into the circuit of a wet string, stratifications may be obtained directly from the galvanic cell, or from the electric machine, as clear and distinct as those from the induction coil.

From this last-mentioned fact it would seem to follow that we cannot, in accordance with the theory of Grove, attribute these luminous strata to the extra current derived from the intermittent action of the contact-breaker. On the other hand, if we are told that the effects produced in the vacuum tube are due to the intermittent nature of the electric discharge, we naturally ask how is it then we have permanent strata of light instead of—what the theory of Gassiot would lead us to expect—an apparently uninterrupted stream of light passing through the tube? Again, if these strata always exist in every luminous discharge from one electrode to another, and are simply made apparent by reducing the intensity of the current, why is it we cannot always, or at least under ordinary circumstances, bring them out either by diminishing the strength of the battery or by using a less perfect conductor of electricity? Let me endeavour then to set before you what seems to me a more probable explanation of these stratifications.

When the circuit of the battery current is closed, an inverse current is excited in the neighbouring secondary coil. This induced current is but momentary, but the effect produced by it is not so. As long as the current in the primary continues to flow in the same direction, the secondary is in what Faraday calls an electro-tonic state. The wire remains stretched, its particles are polarised, the positive and negative elements of the rarefied medium in the vacuum tube are driven different ways. When the battery current is broken, these effects are at once reversed—a current in the opposite direction is immediately set in motion in the secondary wire. Now a current, as you know, travels more rapidly along a solid conductor than through a fluid or gaseous medium. Hence it comes to pass that, when this current falling back has reached the rarefied medium of the vacuum tube, it finds it in an opposite electric state, and consequently meets there with a greater amount of resistance. This is, I think, one reason why these striæ are more readily produced in a vacuum tube connected with the secondary coil, than in one connected directly with the galvanic battery or the electric machine. But this is a point of minor importance. How is it that the current passes from the primary to the secondary wire, which runs parallel to the primary, and which has upon it no current of its own? It passes, so to speak, at right angles, and will have a circular movement upon the secondary wire, and will retain this circular movement in its passage through the vacuum tube. On this account, the light which marks the course of its progress will assume a stratified appearance. As a rule, the more perfect the vacuum—provided a luminous discharge be capable of passing—the more clear and distinct will be the stratifications. Should the tube remain impregnated with the vapour of mercury with which it has been filled, or should it contain a certain degree of moisture, the parallel lines of the current will act one upon another, and the tube will present the appearance, not of striæ, but of a diffused body of light, filling up the entire space, the intensity of the light depending upon the energy of the battery. Proof derived from other sources is not wanting to show that the communication of a circular motion to an electric current passing through a vacuum will have the effect of converting a luminous discharge into striæ. Thus we are told* that, when the discharge which passes through a vacuum tube consists simply of a feeble glow, the supervention of a magnetic force draws a series of strongly illuminated strata from the positive terminal of the tube, and that, when the magnetic force is withdrawn, these strata retreat again in succession as if swallowed up by the positive pole. Again, we are told† that if the electrodes in the vacuum tube be inclosed in glass tubing, open at the end but reaching about one-eighth of an inch beyond the point of the wire, the stratifications are greatly obstructed, if not altogether extinguished. This I take to be the consequence of the circular movement of the current being interfered with. Hence, if the negative electrode alone be protected by glass tubing, stratifications to some extent may be produced at the positive end. But what have I to say to the fact established by Gassiot, that these striæ are not confined to the action of the secondary coil, but can be produced directly by means of the battery current, when its intensity is reduced by the introduction of a wet string into the circuit?* Of course, if these striæ were simply the result of the reduction of the intensity of the current, they might be obtained in other ways as readily as by introducing a wet string into the circuit, such as, *e.g.*, by diminishing the strength of the battery, or by using a less perfect conductor. By the interposition of a wet string into the circuit we bring in, as it seems to me, something analogous to the action of the induction coil. The fibres of the string are interwoven and twisted in such a manner that the current, in following its convolutions, must acquire a circular movement before reaching the vacuum tube, where the effects already described take place. There are, it is true, other cases adduced by Gassiot† in which stratifications are produced by the direct action of the voltaic battery. But, judging from what I see in Noad's "Textbook of Electricity," they are not instances in which the two currents flow through the vacuum tube towards one another in a direct line; but instances of currents conducted in parallel lines into the same side of the tube, so that it is impossible they should meet one another without falling into some kind of circular movement. When the electrodes are very near to one another, in which case there is not sufficient space for circles to be formed between them, there are no stratifications.

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* "Notes on Electrical Phenomena," by Professor Tyndall, p. 88, note 336.

† Noad's "Student's Textbook of Electricity," p. 337.

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* Ibid. p. 340.

† Ibid. p. 239.

Further investigations are needed perhaps before we can come to any determination as to what is the cause of the stratified light which, as we have seen, shows itself in the vacuum tube, under certain circumstances, when the current is transmitted through it directly from the voltaic battery or from the electric machine, and invariably when the current passes through it from an induction coil. As you may gather from what I have said already, I am inclined to believe that it has nothing to do with the series of decompositions taking place in the galvanic trough or the pulsations passing along the conducting wire. These effects are never wanting when an electric current is set in motion, whereas we have no evidence of striæ being on all occasions produced by the passage of a current through a vacuum tube. They are produced by, and mark the passage of, an electric current which circulates through a highly attenuated and resisting medium.

As to the colour of the luminous discharge in the vacuum tube or of the spark in the air, that depends upon the material of the electrodes from which it proceeds, and upon the medium through which it passes. When the spark or discharge is strong the influence of the former prevails to some extent; when it is weak, that of the latter alone. In a tube in which all residuary gas is absorbed, no luminous appearance is visible.

Similar in its action to the electric spark, but endued with a power of incomparably greater energy, is the lightning which discharges itself between the clouds and the earth, or flashes between two clouds which come near to each other being in a different electric state. The path of the electric fluid sometimes stretches out between its extreme positive and negative points many miles in length. It has a width depending upon the nature of the gases and vapours which it meets with on its course. The gases of which the air chiefly consists, viz. nitrogen and oxygen, will be ignited by the passage of the electric current in the same manner as we find that these gases, when inclosed in tubes through which an electric current is passed, ignite and give out each its own peculiar light. The particles of watery vapour floating in the air will by the action of the opposite electric forces be decomposed into their original elements, just as we see, when the electric spark is made to pass through a vessel of water, the water along the line of its passage is converted into its constituent gases. It is not necessary I should point out that the generation of these gases, whereof one is highly inflammable, and the other the great supporter of combustion, must contribute largely to the outburst of flame which marks the track of the electric current, and is accompanied by the peal of thunder rolling over our head.

It is supposed by some that the reverberating sound of thunder is caused by the billows of air rushing in to fill up the vacuum which has been created. We do not, however, so interpret the snap which accompanies the electric spark, though it is evidently of the same nature. Neither do we attribute the loud report which follows the firing of a cannon or of some powder magazine, or the rumbling sound of the earthquake, to this cause, but to the explosive action of the gases evolved. In like manner it would seem that the roll of the thunder is to be ascribed to the explosion which takes place not in one single spot, as when a magazine is fired, but simultaneously or nearly so along the whole line of the lightning's path.

This subject, which is brought before us in consequence of its connection with electricity, has an interest of its own, and I will add a few more remarks upon it. Sound travels more slowly than light. On this account the thunder-clap does not reach the ear till some seconds after the flash of the lightning has departed out of sight; and we may judge by the length of the intervening time how far the lightning is distant from us. Between the sound of thunder when it is heard by one in its vicinity, and when it is heard at a distance, there is a marked difference. A person who is in the immediate neighbourhood of a flash of lightning hears a sharp report, peculiarly sharp when any object is struck by the lightning, but he hears nothing of the roll of the thunder peal. There are here, in fact, two different sounds, proceeding from two different causes. The one is produced by the collision and conflict which take place between the particles which come under the influence of the electric current. This alone is heard by the near bystander. Being a sharper and shriller sound, it predominates over every other within the sphere of its range. The other sound is the effect of the concussion which is produced upon the great body of the outer air in consequence of the sudden expansion which takes place of the gaseous vapours, either heated or decomposed into their constituent elements. These waves of deeper sound, originating in the outer circuit of the compressed air, and lying beyond the bystander, travel far and wide, being the thunder rolling over our heads. It is natural that this sound of thunder should be heard differently by persons in different situations. If we suppose the sound of thunder to be itself the same throughout its course, a person who stood at one extreme end of the line would hear the peal drawn out to its full length. In proportion, however, as he found himself nearer to the middle of the line he would hear a peal of greater force but of shorter duration.* In either case it might be supposed that the thunder would begin at its loudest and end at its weakest, because, though the sound be virtually produced at the same instant at every point of the lightning's path, it comes from the nearest point first and successively from points more and more distant; and in proportion as the distance is greater, the sound would be more faint and feeble. But we know practically this rule does not hold. It not unfrequently happens that the thunder begins and ends with a terrific crash. More frequently it is not the loudest at the beginning—in the case of distant thunder it may be at first scarcely audible—gradually it swells to a crashing sound, and then dies away. And sometimes we have lightning without thunder. It is evident therefore that the action of the general law which governs the transmission of sound, and the impediments which in any particular case may interfere with the report of the thunder reaching us, are not in themselves sufficient to account for the irregularity which marks its course. It is evident that the sound itself varies in character and in degree through the different stages of its progress, and that this variation is due to the more or less explosive nature of the gaseous vapours which the lightning meets with in its passage. Thus we may understand how it is that the sound of thunder rises and falls, now swelling into a crashing sound, now growing fainter until it altogether ceases. When, however, it begins and ends with a violent crash we are led to conclude that the electricity has simultaneously burst forth with accumulated force from the two opposite extremes. These two extremes being separated from one another by a wide interval of space, the loud reverberation proceeding from them will be heard at a corresponding interval of time. Not unfrequently it happens that the whole horizon is illuminated by sheet lightning without any sound of thunder being heard. This may arise from the fact of the gases which are ignited occupying the higher regions of the air, where either no explosion can take place—thus the electric current passes without any explosion through the rarefied medium of the vacuum tube—or where the explosion does take place, but is too slight to make itself heard below. We have the more reason for believing that the discharges of sheet lightning which are followed by no report take place in the more elevated regions of the air because, though we see them on the horizon, and though we sometimes see the clouds over our head with their outlines clearly defined by the bursting out of a mass of light above, we do not find ourselves surrounded by this light on the earth.

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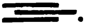
* Ferguson's "Manual of Electricity," p. 98.

LECTURE IX.

THE VELOCITY OF THE PASSAGE OF ELECTRICITY.

The marvellous velocity with which electricity travels presents no difficulty to the adoption of the hypothesis which regards it as a force inherent in matter.

YOU remember I said there were two reasons, which in the minds of many had great weight, in favour of the opinion that electricity is a force which is independent of matter. One reason was that this opinion coincided with a belief that there are other forces in nature of the same kind. I have endeavoured to show that there exists no sufficient ground for entertaining this belief. The other reason was that this opinion seems to furnish a ready explanation of the velocity with which electricity travels. The velocity with which electricity travels is indeed very wonderful. As exemplified in the case of lightning, it is so great that the most rapid motion that can be produced by art appears, as compared with it, to be no motion at all. A wheel revolving with such rapidity as to render the spokes undistinguishable, when illuminated with a flash of lightning is seen for the instant with all its spokes distinct, as if it were in a state of absolute rest; because, however rapid the rotation may be, the light has come and gone before the wheel has had time to pass through any sensible space. Insects on the wing, when electrically illuminated, appear fixed in the air. Let a circular piece of pasteboard be divided into three sections, the one blue, the other yellow, the third red. Cause it to rotate rapidly, and it will appear white, because the colour white consists of the mixture of these colours, and the rapidity of the rotation causes the distinction of the separate colours to be lost to the eye. But the instant the pasteboard is illuminated by the electric spark it seems to stand still, and each colour is brought out as distinctly as if the disk were at rest.* By an ingenious application of the same principle, Wheatstone contrived an apparatus by which he demonstrated that the light of the electric discharge does not last the one-millionth part of a second of time. His plan was to look at the image of a spark, reflected from a plane mirror, which, by means of a train of wheels, was kept in rapid rotation on a horizontal axis. A jar was discharged through a copper wire half a mile in length, interrupted in the middle, and also at the two extremes, so as to give three distinct sparks. The two external sparks kept in the mirror the same relative position, as though they had taken place simultaneously; the middle one was deflected, indicating that it had taken place after the two others, thus, . This experiment is held to be unfavourable to the hypothesis of one fluid passing from one end of the wire to the other. It may for the same reason be said to be unfavourable to the hypothesis of one motive power passing from one end to the other. But the hypothesis which we are dealing with does not suppose the passage from one end to the other of any fluid, or of any motive power. The electric fluid, or electric power, consists, as I understand it, in the particles of the conducting medium acting successively one upon another, by reason of their possessing homogeneous chemical affinities. And since in the case of statical electricity, upon which the experiment of Wheatstone is founded, the two extremes are in a high degree of tension before they are brought into connection by the circuit being closed, it follows that this action must take effect upon each extremity of the conducting wire before the middle of it is reached.

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* Noad's "Student's Textbook of Electricity," p. 62.

Now this velocity with which electricity travels, wherever a pathway is opened to it, may seem to admit of an easier explanation if we suppose electric force to pass along the conducting medium, without being in any way dependent for its transmission upon the action of the particles of the wire one upon another. But instances are not wanting of similar velocity in the transmission of force where we have no doubt about the force being communicated from particle to particle. Thus, when the loosened weight descends upon the head of the pile, and drives its sharpened point into the bed of the river, it is certain the blow must be communicated to all the intermediate particles, passing from one to the other before it reaches the extreme point, difficult though it may be to measure the small interval of time which elapses. Or, to take an example where the parts brought together do not form one compact mass, so that in some sense they are all acted upon together, let a number of billiard balls be suspended in a parallel line so as to touch one another, and let the first of the series be raised up and be then suffered to strike against the second, the concussion will cause the last in the line to fly off at the same instant of time, all the others remaining undisturbed in their places. Yet it is certain the effect of the blow could not have reached the last ball if it had not passed successively through each one of the series. To take one more example, where the transmission is equally instantaneous, and where the body which is acted upon has the least possible cohesion amongst its particles, if the tank which supplies the gas which burns in this room be subjected to any increase of pressure, such is the elastic force of the gas that the flame of every burner will rise simultaneously in this house, and in every other drawing its supply from the same gasometer, even though they should be a couple of miles distant. These, it is true, are examples of the rapid transmission of mechanical force, but they serve to show how almost instantaneously an indefinite number of particles can act one upon another. I have already given instances of the rapid propagation of force through chemical agency, in the case, *e.g.*, of a train of gunpowder being fired, and of the transformations effected in the galvanic trough. However great then the velocity with which electricity travels, it cannot be looked upon as presenting any difficulty to our acceptance of that hypothesis which maintains that electricity is a force developed in bodies which have a chemical affinity for each other, and are therefore capable of acting upon one another, either directly or through a medium which, by reason of its possessing the same homogeneous character with one of the bodies which it unites together, is capable of participating in the same action.

LECTURE X.

STATICAL AND CURRENT ELECTRICITY COMPARED.

Points of similarity and points of dissimilarity between statical and current electricity—No fundamental discrepancy observable between the one and the other—How statical electricity is produced.

HITHERTO I have considered our hypothesis more especially in relation to one kind of electricity, viz. current. Were I to follow out the investigation into all the different forms of electricity, I should lead you into a very wide field of discussion. It will be sufficient if I show, in as few words as possible, that the principal other forms of electricity, viz. statical and thermal, do not differ in their nature from current electricity, and do not present any difficulty to our acceptance of the theory I am advocating. There is, however, another species of electricity, called terrestrial magnetism, which I shall treat more in detail, because it will not only furnish us the means of testing the accuracy of the theory in question, but will put us in the way of arriving at the solution of certain interesting and important problems in science.

Statical, or, as it is frequently called from the mode of its production, frictional electricity, does not differ essentially from current electricity. The one is often converted into the other. Current becomes assimilated to statical electricity whenever there occurs a break in the continuity of the conducting medium which has to be bridged over by the electric spark or flame. Statical is converted into current electricity whenever the prime conductor is brought into communication with the rubber of the machine, or in any other way the circuit is completed. In the example which was given of current electricity we supposed the conducting wire to pass from one plate of the galvanic trough to the other. The same effect would, however, have followed if the wire, instead of being carried from one plate to the other, had been connected with the ground. The telegraph wires are not brought back to the same place from which they started in order to complete the circuit. When they have reached the farthest station, they are made to descend into the earth, which is, so to speak, a great reservoir, capable of absorbing all the electricity which is poured into it. Thus, too, in the case of the electric machine, the circuit may be completed without the prime conductor being put in connection with the rubber, if a connection be established between it and the earth. So far we see that statical and current electricities are similar to one another. They differ in this respect, that the electric force produced by friction is higher in tension, that produced by galvanic action is greater in quantity. The machine can be made to give forth sparks of twelve inches in length; whereas current electricity cannot be maintained if the parts of the conducting wire are divided a quarter of an inch asunder. On the other hand, the thinnest platinum and zinc wires immersed half an inch in acidulated water will produce in two or three seconds as great a quantity of electricity as thirty turns of a fifty-inch plate machine. The results are here very different. The electro-motive force of the machine is very great, as shown by the tension of its electricity; yet it maintains only a very weak current, as will appear if it be conducted through the coil of a galvanometer to the ground. The force of a galvanic pair on the other hand is low, yet the current that results, if made to flow through an insulated galvanometer, is found to be very great. Whence comes this difference? It arises not from any intrinsic difference between the one kind of electricity and the other, but from the difference of the circumstances attending their production. In the galvanic trough, whilst chemical action goes on, electricity continues to be evolved freely. But it has a low degree of intensity, because, as long as electricity has an uninterrupted passage, it possesses no accumulated force, and, as soon as its passage is interrupted, almost all chemical action is brought to a standstill. On the other hand, the electricity given out by the machine is comparatively small in amount. The particles on the surface of the cylinder are excited by the heat which comes from friction. They are not, however, decomposed. The greater part of their energies remains still absorbed upon the elements with which they are chemically combined. The effect therefore produced upon them by friction can never equal the effect which is produced by the decomposition of the elements which takes place in the galvanic trough. But comparatively small though the amount of electricity evolved may be, having no escape it becomes, by the continued action of the machine, raised to a high degree of intensity, and exerts a continually increasing inductive action upon the bodies around, until it breaks through the barrier which restrains it.

If we proceed now to examine into the nature of frictional electricity, we shall find it is essentially the same as current electricity. In the first place, it is necessary for the development of frictional electricity that the two bodies which are rubbed together should contain in their substance elements which have an affinity one for the other. A globe of sulphur was at one time used instead of a glass cylinder, and is said to answer extremely well; but two pieces of sulphur rubbed together would never produce any electrical effect. Two pieces of glass might be able under certain circumstances to do so, but that is because glass is a compound substance, and one piece may have elements excited in it which have an affinity for elements contained in the other. In the next place, it is necessary that the bodies rubbed together should be non-conductors of heat, in order that their external particles may be brought into a fit state to act upon one another. In the case of current electricity, one of the agents in the galvanic cell is already in a liquid state, so that its ultimate particles are easily brought, by the attraction of affinity, into immediate contact with the ultimate particles of the other. It is thus that the oxygen of the water and the zinc plate are capable of entering into chemical combination. In the case of statical electricity neither of the substances which are made to act upon one another is in a liquid state, but the heat generated by friction, though not sufficient to fuse the external particles upon the surface of the cylinder and of the rubber, advances them, so to speak, one stage towards that result. It relaxes the hold which the external particles retain upon the bodies to which they belong, and leaves them free, to a certain extent, to exert the attraction of their affinities upon other bodies. In using the machine the development of electricity is found to be greatly assisted by spreading upon the rubber an amalgam made up of zinc, tin, and mercury, reduced to a fine powder and brought to the consistency of paste by the admixture of lard. This amalgam readily passes, under the influence of heat, into a volatile state, and so, by giving rise to chemical decomposition, developes the action of electricity. In working the machine, it is of great advantage to connect the negative conductor with the ground. Whatever positive electricity is communicated by the excited glass cylinder to those elements of the rubber which are homogeneous to itself thereby passes away, and leaves the negative elements of the rubber to act more freely. Moreover, the effect which follows in the case of the induced cylinder, when it is put in connection with the earth at the same time that it remains under the influence of the charged ball, will take place also here. The area being enlarged from which the negative current is derived, the action of the positive current will be proportionately intensified.

To attempt to determine *a priori* what would be the effect produced by heat upon the compound substances of the cylinder and of the rubber, and to be able to predict what would be the elements that would first be brought into an active state, so as to be capable of exerting externally a chemical influence, might be next to impossible. It is difficult enough, as I shall have occasion to remark when speaking of thermo-electricity, to anticipate the effect that will follow when heat is applied to simple substances, because of the different powers they possess of conducting and absorbing heat; much more difficult must it be to judge what is the result that will follow when heat is applied to substances in the composition of which a variety of elements enter, as in the case of glass, which is a chemical combination of silica, potass, and soda, all of which are themselves compound substances. Knowing as we do that the glass cylinder becomes positively electrified, we may infer that those elements in it which are electro-positive, such as sodium and potassium, are thrown into an excited state, and, being in this excited state, act through the metallic points of the prime conductor upon the brass nob, attracting to themselves its negative or copper element, and exerting an influence through its positive or zinc element upon those objects for which they have an affinity which lie beyond it. How the different phenomena arising out of the mutual action of inducing and induced bodies may be shown to harmonise with this view of the nature of electricity, I have already in a former section endeavoured to prove.

LECTURE XI.

THERMO-ELECTRICITY.

The same observation holds good in relation to thermo-electricity—Its nature is explained.

I PROCEED to thermo-electricity, which I am bound in fairness to notice, because the conclusions which it points to seem at first sight adverse to the theory I am maintaining. I have laid down that electricity arises out of the chemical attraction which different bodies have one to another. But in thermo-electricity we have a current developed, under the influence of heat, in a circuit consisting of one metal only. Again, I have represented electrical attraction as deriving its positive or negative character from the intrinsic relation which different elements have to one another. But from thermo-electricity it would seem as if there existed no such intrinsic relation between them, inasmuch as the same elements stand differently related to one another, according as they are arranged in a chemico-electric or in a thermo-electric order.

The first form under which thermo-electricity comes before us is where one metal being heated produces a current. Take a piece of iron or copper wire. Divide it into two parts, and fix each of them in one of the binding screws of a galvanometer. Heat one of the free ends to redness, and press it against the other end. A current will be generated, passing across the junction from the hot end to the cold. In order to increase the surface of contact the ends of the wire may be coiled into flat spirals. Again, a current may be obtained when two portions of the same metallic wire have different structures, and the part where the change of structure takes place is heated. Thus when one part of an iron or brass wire bent in a ring is hard-drawn, and another part of it is annealed; or when the wire is hammered or twisted in one part, and not so in another, a current will be set in motion if the connection between the two parts be heated by the flame of a spirit-lamp, the current passing from the soft to the hard part.

How are these facts to be explained? In the first place, as I have already had occasion to observe, there are some simple substances, the particles of which seem to adhere to one another, we cannot say by the attraction of affinity, because that term is exclusively used to express the attraction which exists between particles of a different nature, but still by some sort of chemical attraction. This is notably the case with such metals as iron, copper, silver, which, owing to the tenacity with which their particles hold together, are capable of sustaining a great weight without breaking. Now when a flame is applied to one part of a wire of this description, the particles thus affected, being no longer so closely bound together as before, and having no longer their whole attractive force absorbed upon the particular particles with which they are united, are free to exert some portion of it upon such other particles as are brought either mediately or immediately into connection with them. If therefore one end of a wire be heated to redness, and be then pressed against the other end, which is cold, the one part will exert upon the other some sort of chemical influence, and if the wire be insulated will generate a current in it. If the middle part of the wire be heated, it will of course exert a similar influence on the parts on either side. Supposing, however, that on one side the wire offers greater facility for the passage of electric energy than on the other, in that case, if the circuit be complete, the electric current will flow in that direction. As a rule—for there are exceptions arising from the peculiar crystalline structure of some of the metals—a cold wire is a better conductor than a heated one, and a wire of larger size and of denser matter is a better conductor than one which is thinner or more porous in substance, because the particles transmitting the electric current are in the former cases either greater in number or more closely packed together than they are in the latter cases. We may easily understand, therefore, how it is that the electric current, whilst deriving its origin from the chemical attraction which exists between the particles of the metal, and which is brought into play by the application of heat, is dependent nevertheless for the direction which it takes upon the difference which exists in point of temperature or of structure between the one side and the other of the heated wire.

There are, it is true, other causes of electrical influence in operation besides that one which I have just mentioned, but it is not necessary that I should do more than briefly advert to them. Iron and—though in a less degree—copper when heated to redness combine readily with the free oxygen of the air. This observation will have its application to the first of the two instances given above, in which we supposed one end of a wire heated to redness to be pressed against the other end, which was cold. Platinum has not the same affinity to oxygen, and when the two ends of a platinum wire are under similar circumstances pressed together no such effect is produced. The observation which follows has reference to the second of the two instances which I have given.

A flame, when it is applied to a metal wire, acts upon it chemically, not simply by the production of heat and by the disturbance of the relation existing between the particles of the wire—of that I have spoken already—but by the fact of the constituents of the inflammable substance being brought, in their decomposed and nascent state, into contact with the heated metal. How far these secondary sources of electrical excitement may serve to increase and intensify—how far they may have the contrary effect of neutralising and destroying—the action of the first-named cause is a question I do not pretend to determine. We know, however, that carbonic acid is one of the most active products of flame, and that carbon is, in the thermo-electric scale, electro-positive in relation to iron. We should infer therefore that a flame would develop a current in the wire when it acts upon it. If so, we might expect to find that when the iron became heated to redness, and the oxygen of the air, which is electro-negative in regard to iron, began to combine with the metal, a diminution of the strength of the positive current would ensue, if not a change in its direction. Now as a matter of fact a change of this kind does take place, whatever the cause of it may be. The same thing happens also in the case of a thermo-electric pair when either a gold, a silver, a copper, or a zinc wire is coupled with an iron wire. These metals being in the thermo-electric order positive in regard to iron, the positive current passes from them over the heated junction to the iron, but when the junction becomes red-hot the direction of the current is reversed.

I have, I think, shown that there is reason to believe that the current which is generated in the first form of thermo-electricity is to be ascribed to chemical agencies. I may be told perhaps that the agencies which I have pointed out are very insignificant in power. That is true, but it must be borne in mind that the effect which is produced is also insignificantly small.

The second form under which thermo-electricity comes before us is where two dissimilar metals are joined together, and the point of junction is heated. Let, *e.g.*, one end of a bar of bismuth be soldered to one end of a bar of antimony and let the other ends be connected with a galvanometer (Fig 10). Heat being applied to the junction of the two metals, a current will pass from the bismuth to the antimony across the junction, the former metal being positive in relation to the latter. The current generated by heat being applied to the junction of two dissimilar metals is much greater than when heat acts upon a metal in that part where only a difference of structure exists. The force given out by a single thermo-electric pair is comparatively small indeed, but then the amount of force thus generated admits of being augmented indefinitely by a number of pairs being associated together in a single battery. At the same time that the soldered pairs are heated at one end by being exposed, *e.g.* to the radiation of a red-hot plate of iron, they ought to be cooled at the other end by being kept immersed in some freezing mixture. One important object which is gained thereby is the preventing the heat from traversing the whole system. The current flows from bismuth to antimony under the influence of heat, but if the heat extended its influence to both ends it would tend to produce two opposite currents. It is not however to be doubted that the application of cold is productive of a thermo-electric effect similar in character, though inferior in degree, to that which results from the application of heat. We have the proof of this in the action of the thermo-pile, which is a battery usually constructed of a considerable number of bismuth and antimony pairs, and when conjoined with a galvanometer is a most delicate instrument for measuring variations of heat or cold. Now it is to be observed that the thermal capacity of bismuth is less than that of antimony. Being exposed to heat it rises, being exposed to cold it falls in temperature in a greater degree than antimony does.

Consequently, if a bismuth-antimony pair be subjected to the influence of heat, a current of heat will pass from the bismuth to the antimony; if it be subjected to the influence of cold, the current of heat will pass from the antimony to the bismuth, and in both cases the thermal will be accompanied by an electric current. It is true, indeed, that an electric current generated by the application of heat does not always flow in the same direction as the current of heat. The reason of this is that some substances require a greater quantity of heat than others do to raise them to an equal degree of temperature; though it may happen at the same time that their electric properties are stimulated into activity before they reach the degree of temperature required by other substances for this effect to be produced in them. But when the electric current is produced by the abstraction of heat there is reason to think that the electric current will always flow in the same direction as the thermal current, the two metals not being brought in this case into a state in which they can act upon one another, except so far as the disparity of heat which is produced between them causes the one which is higher in temperature to exert an influence upon that which is conjoined with it and is lower in temperature.

I need not dwell longer on this point. What I have to add upon the subject of thermo-electricity regards that more important form of it which is produced, not by the abstraction, but by the communication of heat. In this form it is closely allied to statical electricity, of which I have already spoken. In both we have two substances having an affinity to one another brought into actual contact. In both we have these mutual affinities stimulated into action by heat. Substances which have an affinity to one another do not, as a rule, act chemically so as to combine together, unless one at least of the two be first brought to a liquid state; but they may begin to act electrically upon one another as soon as one of the two substances is advanced one stage on the way to a liquid state; or, in other words, as soon as the external particles of one of the substances are so far loosened from the hold of the adjacent particles as to be free to exert some part of their chemical power upon the substances in the neighbourhood for which they have an affinity. In the case of statical electricity this result is produced by the action of heat, together with the trituration of the surfaces of the two bodies caused by friction. In the case of thermo-electricity, the same effect is brought about by the sole application of heat. The metals are, as to their surfaces, brought by it into a partial state of molecular disintegration, and are thus enabled to act upon each other by virtue of the law of the attraction of affinities.

But we are here met by a serious difficulty. The elements are found to be differently related to each other in the electro-chemical and in the electro-thermal orders. Substances which are electro-positive in the one series are electro-negative in the other. How then can the theory be maintained which identifies electrical with chemical attraction? I took for my example of a thermo-electric pair one formed of bismuth and antimony, and said that, bismuth being electro-positive in relation to antimony, the current when set in motion by heat passes from bismuth to antimony. But I may be told that it is simply an accident that bismuth is electro-positive in relation to antimony, as well in the electro-chemical as in the electro-thermal order. Had I taken a different example, and associated, *e.g.*, bismuth with iron instead of antimony, I should have found that bismuth is negative in relation to iron in the electro-chemical series, positive in the electro-thermal series, and that the electric current set in motion by heat passes from bismuth to iron, *i.e.* in a different way from that in which it would have passed if set in motion by the attraction of chemical affinity.

This is undoubtedly one of the principal difficulties brought against the theory for which I am contending. It will be fully solved if I am able to show that the thermo-electric order of substances is founded upon the chemico-electric order, and that the difference existing between them can be satisfactorily explained. First, however, let me premise that we have not what can be called absolutely an electro-chemical order of metals. They are arranged according to the order in which, when they are immersed in some fluid, and the circuit is completed, the positive current passes from the one to the other. But when they are immersed in some other fluid, they are liable to be acted upon differently.* If then the order of the metals changes to a certain extent when they are compared together through the medium of different fluids, can we wonder that it should change when they are compared together under an influence so totally dissimilar and distinct as that of heat? In the next place let me observe that no substance has what can be called absolutely a positive or a negative character of its own. Not only may the same substance be found to differ in relation to different substances, being at one and the same time positive in relation to one, negative in relation to another, but it may be found, under an alteration of circumstances, to differ in relation to the same substance, being at one time positive, at another time negative in its regard. We have just now seen that the current which passes from silver or copper to iron in a thermo-electric pair is reversed when the iron is heated to redness, and passes then from iron to silver or copper. In like manner we find that iron, nickel, cobalt, when raised to a certain high temperature, change their electric character so as to cease to be magnetic. It is, however, obvious that, from this alteration which under certain circumstances is found to take place in electric action, no argument can be drawn against our theory that the electric action exerted by one body upon another depends upon their chemical affinities; inasmuch as the chemical action which bodies exert upon one another, and which cannot be ascribed to any other cause but their chemical affinities, is liable to just the same sort of variation, the chemical forces being at times modified in their action to a remarkable extent by other physical agencies, such as change of temperature, instable cohesion of parts, and other like incidents.

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* In dilute sulphuric acid, silver is negative towards lead, in a solution of cyanide of potassium it is positive to it.

Out of many illustrations which might be quoted in proof of this point, I will select one of the experiments by which Faraday has satisfactorily established that the electro-motive force of the galvanic pair is due to chemical action. Let two plates, one of copper, the other of silver, be placed in a vessel containing sulphuret of potassium, and let a communication between them and a galvanometer be established. The needle at first deflects in a direction which shows that the copper is the positive element of the pair. By degrees it reverts to its original point, and then deflects in the opposite direction, showing that the silver is now the positive element. After a time it returns once more and points in its first direction, and goes on thus changing from one direction to the other. Now, if we examine the plates during these changes, we shall find the sulphuret of copper is formed when the copper is positive, the sulphuret of silver when the silver is positive. The electric current changes because the chemical action changes. And, though the chemical affinities between the two plates and the liquid remain the same, the chemical action changes because each plate in succession is rendered for a time inactive by becoming coated with its sulphuret. If, therefore, we should suppose the electrical action which takes place between bodies to be produced by their chemical properties, it would by no means follow that under different circumstances this electric action might not undergo a change, inasmuch as we find that under different circumstances the chemical action produced by these properties itself undergoes a change. Lastly, let me add that what has been said of the order in which the elements stand when arranged electro-chemically, applies also to the order of the elements when arranged in an electro-thermal series. It cannot be looked upon as absolutely but only as relatively true. Dr. Noad's manual gives two lists of metals in an electro-thermal order, one by Dr. Matthiessen, the other by Professor Cumming, differing one from the other to a considerable extent. We cannot be surprised at this discrepancy when we learn that different methods have been employed by these experimentalists in determining the thermo-electric character of the metals. Matthiessen has taken silver as his standard, and has compared each of the other metals in succession with it. Cumming has compared the several metals one with another. Each method has its advantages and disadvantages. I shall myself, in instituting a comparison between the electro-thermal and the electro-chemical order of metals, make use of the list which Dr. Matthiessen has given. Dr. Ferguson in his "Manual of Electricity" gives no other. Balfour Stewart in his "Treatise on Heat" has a shorter list, which, as far as it goes, corresponds with Dr. Matthiessen's. It may, I think, be doubted indeed whether any large number of elements can be either electro-chemically or electro-thermally arranged so that each one as it stands in the series shall be positive to all below it, negative to all above it. For example, if, with Dr. Matthiessen, we take platinum to be in a certain degree positive, zinc in a certain degree negative in relation to silver, it does not follow from this that if platinum and zinc be directly compared together, they will be found to hold the same relative position in regard to one another. It does not follow, I say, that where it is a question not of magnitude, but of affinity, the relation which two substances have to a third will express the relation they have to each other. Having made these preliminary remarks, which go beyond what is needed by my argument, I proceed to show that they who admit the electro-chemical order of the elements to be founded upon the affinities which bodies have for one another, are bound to admit the same thing in regard to the thermo-electric order of elements, because the two series do not differ from each other except so far as the metals have their powers of affinity developed in a different degree under the influence of heat. To put the truth of the matter to the test, take two elements of the electro-chemical series, apply heat to the point of junction between them, and, completing the circuit, see in what way the electric current which is generated flows. It will be found either that the two metals stand in the same relation to one another as before, or, if they do not, that the metal which is transferred from the negative state in the electro-chemical order to the positive state in the electro-thermal, is the metal which under the influence of the same degree of heat is raised to a higher temperature, and is brought more quickly than the other metal conjoined with it from an inactive to an electric state. Bismuth, it will be seen, is transposed from a comparatively low place in the electro-chemical scale to the head of the list in the electro-thermal order of the elements. Iron, on the other hand, falls from a high position in the electro-chemical series nearly to the lowest place in the electro-thermal scale. Nevertheless it will be found that bismuth displaces no metals but such as rise more slowly in temperature than itself, and that iron is not displaced by any metals but such as rise in temperature more rapidly than it does itself. Let us then unite these two metals in a pair, in order to see what is the effect produced by heat upon them. In the first place iron is a much better conductor of heat than bismuth. Therefore the heat communicated to the two bars at the point of junction will in the case of the iron bar pass away more rapidly. But this is not the only, neither is it the principal cause why the iron bar rises more slowly in temperature. If we put a coating of wax upon the free ends of the two bars before heating the point of junction, we shall find that, though the iron is a better conductor, the wax melts at the end of the bismuth before it melts at the end of the iron bar. Why is this? It is because iron requires a much greater quantity of heat than bismuth does in order that it may be raised to the same temperature; in other words, the specific heat of iron is greater than that of bismuth. In order then that we may be able to understand how the electro-chemical order of the elements becomes transformed into the electro-thermal order, we require to know two things, viz. first, the electro-motive force of the attraction of affinity between the different elements, and secondly the capacity which they have for conducting and absorbing heat. We shall make, I think, sufficient allowance for both the conducting and the absorbing powers of bodies if we take the specific heat, not of equal volumes, but of equal weights. I give below a table, taken from Stewart's valuable "Treatise on Heat," showing the specific heat of the different metals. I subjoin thereto tables showing the different order of the metals when they are arranged electro-chemically and when they are arranged electro-thermally, in order that you may be able to compare them together.

Table showing the electro-chemical and the thermo-electric order of the different elements, as well as their relative specific heat.

Electro-Chemical Order. Noad's "Textbook"	Specific Heat. Of equal weight	Thermo-Electric Order of Elements		
		Matthiessen	Becquerel	Cumming
Potassium	·1696	Bismuth	Bismuth	Bismuth
Sodium	·2934	Cobalt	Nickel	Mercury
Magnesium	·2499	Potassium	Platinum	Nickel
Aluminum	·2143	Nickel	Palladium	Platinum
Zinc	·0955	Sodium	Manganese	Palladium
Iron	·1138	Mercury	Silver	Cobalt
Nickel	·1091	Aluminum	Tin	Tin
Cobalt	·1070	Magnesium	Lead	Lead
Lead	·0314	Lead	Copper	Brass
Tin	·0562	Tin	Gold	Gold
Bismuth	·0308	Copper	Zinc	Copper
Copper	·0951	Platinum	Iron	Silver
Silver	·0570	Silver	Antimony	Zinc
Mercury (solid)	·0319	Zinc		Iron
Platinum	·0324	Iron		Antimony
Tellurium	·0474	Antimony		
Antimony	·0508	Tellurium		

The inspection of this table shows at once that the thermo-electric order of elements is not simply the order in which they stand in relation to the influence of heat upon them. We find, for instance, potassium and sodium represented by high numbers in the table of specific heat; in other words, they are raised but slowly in temperature under the influence of heat. Nevertheless they are among the highest in the thermo-electric, as well as in the electro-chemical list of elements. Again, in its capacity for conducting and absorbing heat, iron stands above antimony and bismuth. Yet in the thermo-electric series it is positive in regard to the one, negative in regard to the other. On what then is the thermo-electric order founded? I have endeavoured to show that electric action arises out of the chemical affinities which bodies have one to another. But, although bodies have mutual affinities to one another, they cannot act upon one another before they are brought into a fit state of preparation. Now when they are brought into this state by the application of heat, since heat affects bodies differently, raising one body in temperature more rapidly than another, it follows that it will modify to some extent the action of the affinities of bodies upon one another. We have a table showing us the relative specific heat of the different metals. If we had a corresponding table showing the relative electro-motive force of the chemical affinities of the different metals, we should then be able, by comparing the two, to make out how the electro-chemical order of the metals becomes changed into the electro-thermal. Unfortunately we have no such table marking the relative strength of the affinities of the different metals one to another. I must content myself, therefore, with saying that, the relation which the elements have to one another in the electro-chemical and in the electro-thermal series being founded upon the same principle of the attraction of mutual affinities, the order of the elements in the one case will be the same as in the other, except so far as heat, by raising the temperature of different bodies in unequal degrees, will have the effect of bringing the affinities of some more powerfully and rapidly into play than the affinities of others. If then we find that, *e.g.*, potassium and sodium, which stand high in the electro-chemical list of elements, retain in the electro-thermal list a precedence before metals which rise more quickly in temperature under the influence of heat, we know this must be because the chemical force of the affinities of these two metals is such that it needs scarcely any increase of heat to call them into activity. If we see that iron, which is electro-positive in regard both to antimony and bismuth in the electro-chemical series, remains positive in regard to antimony in the electro-thermal series, whilst it becomes negative in regard to bismuth, although in the table of specific heat it stands higher than both of them—this proves that the preponderance of the affinitive force of iron over the affinitive force of antimony in the electro-chemical order is so great that it still remains in the ascendant, notwithstanding the gain to the side of antimony which is derived to it from the greater effect which heat produces upon it; whilst, on the other hand, it appears that the preponderance of affinitive force which iron has over bismuth in the electro-chemical order is more than counterbalanced by the greater stimulus which the affinities of bismuth receive from the application of the same heat to the two metals. If then we would realise the greatest amount of thermo-electric power, it is necessary for us to couple together two metals having such a relation one to the other that heat will have the effect of freely developing the affinitive force which belongs to both, without reversing the order in which they stand to one another in the electro-chemical order. Thus in an electric pair formed of bismuth and antimony, heat, whilst acting freely on both, produces a greater effect upon the affinities of bismuth, which were already in the ascendant in the electro-chemical order.

As then we do not know what is the relative strength of the mutual affinities existing between different substances in their primary state, we cannot determine beforehand by inspecting the table which shows their relative thermal capacity what changes will be brought about under the influence of heat; we can only say that, whatever change from the electro-chemical order does take place, it will be found that the metal which is displaced rises in temperature and passes into an active electric state more slowly than the metal which displaces it. Comparing together the electro-chemical and the electro-thermal tables, you may, it is true, meet with one or two apparent exceptions. Mercury in regard to lead, cobalt and nickel in respect to zinc, and tellurium in relation to antimony, do not accord with this rule. Of tellurium we know very little; it is of rare occurrence, and belongs to a class intermediate between those of the metallic and of the non-metallic elements. Mercury under the influence of heat at once liquefies, and passes into a more active chemical state, and may therefore be dismissed from further consideration. But my answer to these, as well as to the other instances named above, is that the tables before us are admitted to be no more than approximations to the truth. Before these particular cases can be admitted to be exceptions to the general rule, it is necessary that the electro-chemical and the electro-thermal relations which these substances have to one another be satisfactorily determined. Should they prove, however, to be exceptions, they cannot be regarded as being anything more. They cannot invalidate a rule which is established and confirmed, not only by the behaviour of a much larger number of elements, but by the behaviour of these elements also in all other circumstances but those given above.

Before leaving the subject of thermo-electricity, I will add a word or two upon a phenomenon of an interesting character to which attention is directed in the manuals before me. We have seen that when heat is applied to the junction of two dissimilar metals like bismuth and antimony, a current is produced in one direction, and when cold is applied a current is produced in the opposite direction. We are told that, similarly, when an electric current is made to traverse such a compound metallic conductor, in passing from antimony to bismuth it gives out heat, in passing from bismuth to antimony it absorbs it. First, when the current passes from antimony to bismuth heat is generated. We should expect this would be so, because bismuth is not so good a conductor of electricity as antimony, and we have seen before that when we have a conducting chain formed of alternate links of silver and platinum, the platinum links, which are not so good as a conductor, may become red-hot from the passage of the current whilst the silver links remain dark. The difference between the conductivity of bismuth and that of antimony may in part account for the amount of heat which is evolved. There is, however, another cause contributing to the same result. When the junction between the antimony and bismuth (Fig. 11, *m*) becomes heated by a current passing from *e′* to *e*, thermo-electricity is called into action between the two metals. A current is set in motion flowing from bismuth to antimony, *i.e.* in a contrary direction to the galvanic current, and the additional obstacle thus created to the passage of the galvanic current will cause a still further development of heat. We may in this manner explain the evolution of heat which takes place when the galvanic current traverses the conductor from antimony to bismuth. But how are we to account for the absorption of heat which takes place when the current passes from bismuth to antimony? In the first place, it is manifest that, the conductivity of antimony being greater than that of bismuth, there will be no accumulation of electricity, and consequently no increase of heat, produced by the passage of the galvanic current from bismuth to antimony. But though this may explain why there should be no increase of temperature at the junction of the two metals (Fig. 11, *m′*), it does not explain why there is a diminution of it. The cause of this absorption of heat is to be found, it seems to me, in the double antagonistic attraction which is here called into play. The galvanic current passing along the conductor from antimony to bismuth raises, as we have seen, the temperature of the latter, and produces a thermo-electric action at the junction of the two metals (Fig. 11, *m*). The circuit being complete, this thermo-electric current will flow from end to end in the opposite direction to the galvanic current. But the bismuth rod, raised to a state of electrical excitement, is brought through the conducting antimony rod, A′, into connection with the negative element of the galvanic trough, for which it has a strong affinity; and the consequence of this is that, whilst we have on one side of the bismuth rod a thermo-electric current set in motion from bismuth to antimony, we have on the other side of the bismuth rod a chemico-electric current set in motion from bismuth to the negative element of the galvanic trough. Where the action of these two antagonistic forces is most nearly balanced there will be absorption of heat. For heat arises from a certain molecular motion of the ultimate particles of bodies, and when these particles are drawn simultaneously in two opposite directions, that motion is at once interfered with and reduced. In the same manner, it is found that a wire which is stretched by having a weight suspended from it is lowered in temperature.

This phenomenon of the evolution of heat when a galvanic current passes along a conductor from antimony to bismuth, and of the absorption of heat when it passes from bismuth to antimony, thus admits, as it seems to me, of an explanation in accordance with the theory of electricity I am advocating, and I do not myself know in what other way it can be explained. It is sometimes said, indeed, that the cold produced in one part of the system is nothing more than compensation for the heat which is emitted in another part. But that does not explain to us why heat is produced in one particular part, and why cold is produced in another particular part. Neither is this answer altogether consistent with the statement commonly made, that the total amount of heat generated in the conducting wire, together with that liberated in the battery, make up the exact equivalent corresponding to the quantity of fuel consumed in the galvanic trough. Again it is said, in explanation of this phenomenon, that an electric current denotes energy, and that, where there is no access to the system of energy in any other form to serve for the production of a current, it is necessary that energy in the form of heat should be abstracted from the system for the purpose. But admitting it to be true that an expenditure of energy in one form or another is necessary for the accomplishment of any work, one may ask why in this particular case the galvanic trough fails to supply that energy which is required for the transmission of the electric current which it generates; or, in the hypothesis of the galvanic trough failing to supply the energy which is required, why in this particular case the energy of heat should be transformed to make up for the deficiency? For surely, as a general rule, the electro-motive force generated in the galvanic trough either is sufficient for the transmission of the current which is set in motion, and in that case no abstraction or conversion of heat would be required, or it is not sufficient, and in this latter case the current would cease to flow.

LECTURE XII.

ELECTRO-METALLURGY—CLEAVERAGE.

Illustrations taken from metallurgy and cleaverage in confirmation of the chemical theory of electricity.

I HAVE said enough to show that the various forms of electricity do not differ from one another essentially, but that the difference which exists between them arises from circumstances modifying, in particular cases, the general law of attraction which bodies exercise upon one another. I will adduce an illustration in point, taken from electro-metallurgy, which is the art of depositing electrolytically a coating of metal upon some other surface, where the coating is either intended to be afterwards removed, as when we wish to take the impression of a seal, or is intended to remain, as when articles formed of a baser metal are plated with silver or gold.

The manner in which this is done will be best understood by taking a particular instance. Suppose we want to take the copy of a seal in copper. An impression of it is first taken in gutta-percha, or some other substance capable of giving us a clearly defined impression. As gutta-percha is a non-conductor of electricity, it is necessary to brush it over on the side which bears the impression with plumbago or some other conducting substance. Having inserted a wire in the mould, we connect it with the negative pole of the galvanic trough. Taking a copper plate, we connect it in like manner with the positive pole of the trough. The mould and the copper plate being now dipped into a vessel containing a solution of the sulphate of copper, a current at once passes from the one to the other, the copper of the solution begins to deposit itself on the impression, first in the vicinity of the wire, by degrees over the whole conducting surface. The process being allowed to go on for a sufficient length of time, a layer of copper is formed as dense and homogeneous as the best-hammered metal. The impression being then taken out, the copper deposited on it, forming a strong plate, may be removed by inserting the point of a knife between the mould and the edge of the plate.*

The example here given, besides explaining the nature of metallurgy, confirms the truth of the theoretical views which have been put forward on the subject of electricity in general. It shows in the first place that the origin of electric force is the attraction of affinity which exists between different bodies. In this case the decomposed elements in the galvanic trough act upon one another—the oxygen being the negative, the hydrogen the positive element—through the conducting medium. It shows in the second place that this electric action cannot be maintained unless the conducting medium be throughout homogeneous with one of the two elements. Gutta-percha is an organic substance having little or no affinity either to oxygen or hydrogen; it blocks up the way of the passage of electricity, and it is not until plumbago takes its place in the circuit that the electric current can pass. Finally, this example teaches us that, under the influence of chemical and electrical agencies —for the two are intimately connected together—not only do heterogeneous elements combine and form one substance, but homogeneous elements combine and form one body. The copper held in solution in the bath in which the impression of the seal is suspended begins, as soon as the electric circuit is closed, to deposit itself upon the surface of the plumbago which is in conducting communication with the oxygen element of the galvanic trough. The metal itself is a good conductor, and therefore, when the whole surface of the plumbago has been incrusted over, the deposition of copper still goes on, and its particles unite together to form a solid plate. Under what power are these particles made to unite together? By the attraction of cohesion you will say. But in the case before us what does this mean but that homogeneous elements, under the influence of some other body acting upon their affinities, are drawn so closely together that they remain afterwards by the force of gravitation welded together in one body? And this effect is produced by the agency of electricity perhaps more commonly than by any other cause. To what but the passage of electricity are we to attribute the formation of the metal veins, and in many cases the vast mineral beds, which lie beneath the surface of the earth?

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* Ferguson's "Manual of Electricity," p. 220.

Again, we find in the case of substances formed of heterogeneous elements chemically combined together, that when the union of their parts is broken or disturbed by cleaverage or by compression—if the substances are sufficiently non-conducting to give time to note the effect produced in them—they exhibit signs of the presence of electricity. Thus if a plate of mica, which is of crystalline structure, be cleft asunder, one of the divided faces shows positive, the other negative electricity. Similarly we find that when compound substances are decomposed into their constituent elements, these elements are in an electric, or what is called a nascent state, being ready, from the excitation of their affinities, to enter into any new combination which may offer. I might easily multiply facts, but I think those which have been already adduced are amply sufficient to prove the close intimate union which exists between electrical and chemical action.

LECTURE XIII.

GENERAL DISTRIBUTION OF ELECTRICITY THROUGHOUT THE EARTH.

Evidence of electrical energy pervading the animal and vegetable as well as the mineral kingdoms—Concluding remarks.

I ALLUDED at the outset to the widespread influence of this most subtile and mysterious agent. It would be altogether a mistake to suppose that the action of electricity is wholly or principally absorbed upon the primary elements of substances, or upon those belonging to the mineral kingdom, although it is almost exclusively to its operations on inorganic matter that I have had occasion to direct your attention. In reality, its action extends alike to every part of the animal and vegetable kingdom. It is not required for the purpose I have had in view, neither is it in my power to take up this further branch of the subject. I will simply cite the glow-worm, the firefly, the electric-eel, the electric-fish, as particular instances of animal life in which electric power is in a remarkable manner displayed. But in truth the nerves and sinews which pervade the bodies of all living animals may be likened to the wires of an electric apparatus. Electricity courses along them, and, by the contraction and rigidity which it produces in them, may be said to be the immediate cause of the motion and sensation which follow therefrom. In like manner, we have evidence of the working of electricity in the vegetable world, more particularly in the springtime of the year, when the chemical processes of germination are in full operation. Organised bodies, to which class plants of course belong, are not as a rule good conductors of electricity. Nevertheless, as long as the plant remains full of sap, electric currents are transmitted through it from one extremity to the other. The plant serves, moreover, as a conducting medium of the opposite electricities of the earth and the air. Out of many instances which might be given of the secret working of electric energy, take the following:—When by a storm of wind and rain sweeping over the cornfield the growing crop whilst yet green has been beaten to the ground, it will, by the force of the electric current passing through it from the earth into the air, gradually lift up its head once more; but if it be laid low after it has become dried and sapless, there is no possibility of its rising again.

Electricity is not, however, confined in its sphere of action to the face of the earth, it penetrates the regions of the air; it extends, as we shall see when we come to the second part of our subject, beyond the farthest bounds of the earth's atmosphere. I will content myself here with adducing a familiar illustration of the vast field over our head through which its influence makes itself felt. In the heat of summer, the crops of grain standing white upon the plain ready for the sickle, the sap ceasing to flow in the trees of the forest, and all the respiratory organs of the earth's electricity being choked up, whilst the dark clouds charged with the electricity of the heavens hang in the air, oppressed nature cries, and cries not in vain, for relief. Suddenly the storm bursts forth. The wide expanse of the heavens is lit up by one vast sheet of lightning, or the vivid flash darts down to the earth, striking perhaps some lofty oak and rending it in twain. Above the raging tempest the voice of the thunder makes itself heard, peal following after peal, whilst the rain descends in torrents. The storm subsides, but not until the perturbed state of the atmosphere has been brought back to its normal condition, and the earth, under the influence of it, has begun to recover its pristine vigour and freshness. Now if electricity can act through so wide a space with so much energy and force, we cannot doubt that its silent influence will reach to far greater distances. But, in bringing forward this example, I have wished at the same time to direct attention to the fact that the destructive energy accompanying electrical phenomena is for the most part due to chemical rather than to electrical agencies. Electrical action may be said to cease, and to give place to chemical action, when the lightning passing through the air decomposes the vapours which it meets with on its way, and causes the constituent elements into which they are resolved to explode with a loud reverberating noise. Again, when the lightning, issuing from the charged cloud and seizing upon so bad a conductor as the tree is, decomposes and ignites its sap, which it makes the channel of its course to the earth, and which, by being thus suddenly expanded and heated, rends asunder and chars the stubborn trunk, the effect which takes place, if begun in electrical influence, has its ending certainly in chemical action. It must be admitted, however, that it is, in a manner, impossible to draw the line of demarcation between the action of these two powers, which are of the same origin, the same nature, and merge the one into the other.

I conclude then, as I began, with the remarkable words used by Sir Humphrey Davy (*Phil. Trans.* 1826): "Chemical and electrical attractions are produced by the same cause, acting in one case on particles, and in the other on masses of matter; and the same property, under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations." Electrical and chemical attraction have their origin alike in the mutual action of the excited affinities of bodies brought into contact or into communication one with another. When the action leads to the decomposition of the bodies into their primary elements, or to the reconstruction of elements into new forms of substance, the effect produced is said to be chemical. Modifications and changes of this kind are going on continually in the world around us. The transformations which take place in the galvanic trough are examples of similar changes brought about artificially. On the other hand, when one body acts upon another in the mass by virtue of the mutual affinities existing between them, the effect produced is said to be electrical. It is thus the pith ball and the excited brass ball are drawn into contact. It is by the operation of the same law the dark masses of differently electrified clouds attract one another. It is in like manner owing to electrical attraction, as it seems to me, that the seed when cast into the ground shoots its root in one direction—viz. into the earth, which offers it food and nourishment—and shoots its stem in another direction, viz. towards the air and light, which attract it. In a word, electrical agencies are, just as chemical agencies, continually at work in nature. Under ordinary circumstances two bodies under the influence of electricity are carried directly towards one another, but, whatever the movement given to one body, a corresponding movement will take place naturally in the other body. We have an example of this in what is called the magnetism of rotation. If, *e.g.*, a metallic plate be made to revolve immediately over a magnet, a sheet of paper intervening between the needle and the disk, the reaction of the electric currents produced on the revolving plate will cause the needle to rotate in the same direction; or, *vice versa*, if the magnet be made to rotate, it will cause the plate to rotate after it. I need not say more upon this point at present, because I shall have an opportunity of considering it in treating the next part of my subject. But, it may be asked, have we any instance of a similar kind of movement being produced in bodies on the earth through the action of electricity? The heliotrope or sunflower turns always with the sun. It is doubtful, however, whether this is strictly a parallel case, and whether it should not rather be looked upon as an instance of a body which by its sensitiveness and fulness of form allows free scope to the attractive power which the sun exerts upon it in a direct manner. We have at all events, in the tornado and the waterspout, which are electric whirlwinds on land and at sea, instances which are strictly in point. By a circular movement which is produced by electrical agencies in the atmosphere, a circular movement is communicated to the particles upon the surface of the waters of the sea, or of the sands of the desert; whilst, in addition to the corresponding gyrations which take place between the agitated surface of the land, or of the sea, and the dense stratum of cloud hang ingover it, there is also an attraction causing an approximation between the one and the other, the descending cone of the cloud sucking up the foam of the sea, and the dust of the earth, which are whirled round with tremendous force. This same attraction, though it has not the power to manifest itself, may well be supposed to exist between the revolving magnet and the conducting plate.

Again, the effect which is produced by one body upon another is electrical when their mutual affinities exert their influence upon one another not immediately but at a distance, through the interposition of some conducting substance. Thus the charged ball acts electrically upon the insulated brass cylinder. Thus the atom of hydrogen which is liberated in a nascent state upon the surface of the copper plate in the galvanic trough acts upon the atom of oxygen deposited upon the zinc plate, for which it has a strong affinity. Can we give examples of the same kind of electric action in the operations of nature? The impression made on the retina of the eye by the light proceeding from any external object ot vision, and in like manner the percussion produced upon the tympanum of the ear by the undulations of sound are transmitted by the conducting medium of the nervous filaments and of the spinal cord of the body to the brain, where the act takes place of our mental perception of those things which are accomplished in the outer world.

Regarding then, as I do, the electrical and chemical powers as identical in their nature, and as being, the one no less than the other, the result of the mutual action of the affinities existing between different bodies, I reply to the questions that were proposed by saying, first, that there are not many kinds of electricity, but that there is only one kind, which is, however, subject to various modifications; secondly, that electricity is not a fluid, nor a material substance of any kind, but a property or power—a property or power not existing apart from or independent of matter, but by the original constitution of things inherent in matter, pervading all substances, and, in a greater or less degree, energising in all; and that because, in the third place, electrical being in its nature identical with chemical power, they differ from one another only in degree—in the circumstances under which they act, and, to the same extent, in the nature of the results which they produce.

MAGNETISM.

MAGNETISM.

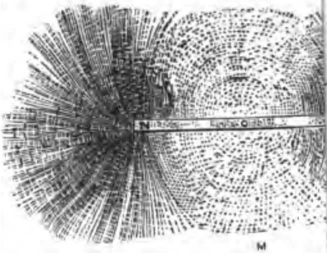

Fig. 12.—N, North pole of magnet. S, South pole. M,

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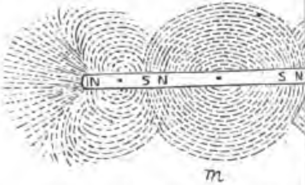

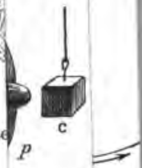

Fig. 12i.—NNN, Consecutive north poles. SSS, Conse
points. ***m*,** Magnetic lines of force.

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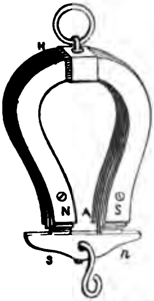

Fig. 13.—H, Horseshoe magnet. N*n*, North poles. S*s*, South poles. A, Armature or keeper.

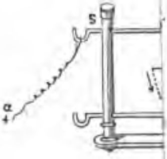

Fig. 14.—*ab*, Elect
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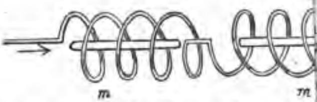

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Fig. 15.—*m*, Bar magnetised like the earth. *m′*, B

MAGNETISM.

LECTURE I.

THE TELEGRAPH AND THE MAGNETIC CURRENT.

How the electric telegraph transmits its message explained—The direction in which the magnetic current flows.

HOW does the telegraph transmit its message from one part of the world to the other? This is done by the current of the electric wire acting upon the current of the magnetic needle. Two currents in close proximity, flowing in different directions, will act one upon the other, and the course of one of them, or of both if they are free to move, will be changed.

The electric current of the telegraph wire flows, let us suppose, in a direct line north and south. Place the magnetic needle in a parallel line immediately under the telegraph wire. The magnetic needle points, as you are aware, north and south, but the current which circulates upon it flows east and west. It will have to be explained hereafter why it is that the current flows on the lower side of the magnet from east to west, and on its upper side from west to east. At present we merely deal with the fact. We have then here two currents—one running north and south, the other east and west—brought into close proximity to each other. By the laws of electro-dynamics, these currents will act one upon the other. But the current upon the telegraph wire cannot change its course, because the wire is fixed and immovable; therefore the current upon the magnetic needle must do so, and the point of the needle being free to move will turn either to one side or the other. In accordance with the laws which govern the mutual action of currents upon one another, that movement will be (supposing the magnet to be placed under the conducting wire) an inclination of the north end of the needle to the west when the electric current runs from south to north (Fig. 14), and an inclination of the north end of the needle to the east when the current flows from north to south. A movement the reverse of this will take place if the magnetic needle is placed above instead of below the telegraph wire.*

Given then these three different positions which the needle may take up—viz. the first parallel with the telegraphic wire when no electric current passes along it;

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* When the magnetic needle is placed parallel to the telegraph wire, along which a current passes from south to north, no motion of the needle will take place in the horizontal plane, but, other circumstances remaining the same, its north pole will be depressed when the needle is placed on the east side of the wire, and will be elevated when the needle is placed on the west side of the wire; in a word, the needle shows a tendency to rotate round the telegraph wire. The actual rotation of the needle round a conductor of electricity when the conductor is fixed and the needle free to move, and the rotation of the conductor round the needle when the needle is fixed and the conductor free to move, have been effected by Faraday.

the second a deflection of the needle to the west when the electric current runs from south to north; the third a deflection of the needle to the east when the current flows from north to south, it is easy to understand how an entire alphabet may be constructed out of the combinations it is possible for us to make of them. One, two, three movements to the right would give us three different letters. One, two, three movements to the left would furnish three more. One to the right, with one, two, three to the left would add another three, one to the left, with one, two, three to the right would bring the number up to twelve. By the help of other combinations an entire alphabet would be speedily completed. I have given here an indication merely how an alphabet might be constructed, not one of the actual methods which have been found most convenient in practice.

It was Oersted, a Danish philosopher, who, in 1819, first discovered that when a magnetic needle is brought near to the connecting medium of a closed volatic circuit, it is immediately deflected from its former position and made to take up a new one depending upon the relative positions of the needle and the conductor. This discovery laid the first foundation of electro-magnetism. It is, however, to Ampère we are indebted for that theory which explains the direction of the current circulating upon the magnet, a theory which commends itself to our acceptance * because it is sustained by the highest mathematical investigation, and furnishes a satisfactory explanation of all the mutual actions of

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* Noad's "Student's Textbook of Electricity," p. 258.

magnets and electric currents, and of magnetic and electro-magnetic phenomena. According to this theory the current circulates on the magnetic needle or bar, as has already been stated, not north and south, in which direction the magnet points, but east and west, in which direction the magnetic current flows upon the earth. And it may be added that the reason why the magnetic current flows upon the lower surface of the magnet from east to west, is because the current flows in that direction on the upper side of the earth, with which the lower side of the magnet is in close proximity; and the reason why the ends of the magnet point north and south is because the magnetic current—the magnetic current, like the electric, is a double current—flows on the lower side of the magnet, from one end of it to the other, from east to west. As, however, this current in going round the earth travels from east to west on its upper side, whereas in going round the magnet it travels from east to west on its lower side, it is clear that it travels round each in a different way. Were we to stand facing the north pole of the earth and the north pole of the magnet, we should in the case of the former see the current go round in the direction of the hands of a watch, and in the case of the latter in the opposite direction.

I must not omit to state that Ampère's theory concerning magnets supposes the current to flow not merely round their surface on every side, but round all the particles of which their mass is composed. In support of this view certain facts, might be adduced. Thus, *e.g.*, it is admitted that under the influence of the magnetic current an iron bar is lengthened in an appreciable degree. Now this fact, it is evident, accords better with the hypothesis that the current pervades the entire substance of the bar, than with that which limits its action to the outer particles upon its surface. As, however, facts may be brought which seem to tell the other way, I take no more of Ampère's theory than that which appears to be indisputably proved.

I ought also to mention that Ampère is generally supposed to have held the magnetic current to be a material substance. For myself, I agree with those who hold that it is not a material substance, but a force generated in material substances, and acting through them as a medium. This difference of view as to the intrinsic nature of the electric and magnetic elements does not, however, in any way affect our conclusions as to the external relations which exist between them, *i.e.* as to the manner in which their forces are exerted, and the practical results which follow from the action of these forces one upon another.

LECTURE II.

THE POLES OF THE EARTH, AND OF THE MAGNET.

The difference between the north and south magnetic poles; as also between the poles of the earth and those of the magnet.

MANY look upon the north pole of the earth, and the north pole of the magnet as dissimilar poles, and recommend the adoption in this country of the nomenclature which is common abroad; as, for example, in France, where that end of the magnet which we call the north is called the austral pole, and that which we call the south is called the boreal pole. Of course, if the only difference between the north and south pole of the magnet were that the current flows at one pole from right to left, and at the other pole from left to right, it would be true to say that what we call the north pole of the magnet is a south pole in relation to the earth, and the sooner we changed our terminology, and called it the south pole, the better. But, I would ask, is this the only, is it the chief difference which distinguishes the one pole from the other? Admitting that the direction in which the current flows at one end of the magnet is always different from that in which it flows at the other, have we not reason to believe that it is upon the nature of the current, much more than upon its direction, that the character of the pole depends? Let me assume for the present that the current which circulates upon the earth from east to west until it reaches the north pole, is a positive current. This current communicates itself to the magnet, and circulates upon it from east to west, until it in like manner reaches the north pole of the magnet. We know from the electro-dynamic laws that two currents which flow in such close proximity as one upon the upper surface of the earth, the other upon the lower surface of the magnet, must be alike in character, as well as in direction, otherwise the magnet which is free to move would alter its position. We are thus led to the conclusion that the pole of the earth and that of the magnet, which point in the same direction, agree in the character of the magnetic current which flows about them, but differ in the manner in which it circles round them, so that there would seem to be as much, if not more reason why we should call them by the same name, rather than by different names. If we compare, on the other hand, two magnets together, we shall find that the corresponding poles agree, not only in the character but also in the direction of the current which flows round them. For either they have both been magnetised by the magnetising power of the earth, or else by a magnet deriving its magnetic power from that source, and in either of these cases the relation existing between the character and direction of the currents will be the same; or they have been magnetised in different ways—*e.g.*, one has had an electric current carried round it from right to left, the other has had a similar current carried round it from left to right —in which case that magnet, which may be said to be anomalous, as departing from the common type, will sooner or later, under the counteracting influence of the earth's current, either have the direction of its current reversed, or else lose altogether its magnetic properties.

But what precise ground have we for supposing that the current which flows to one end of the magnetic needle or bar is positive, and the current which flows to the other end is negative, seeing that both ends of the needle alike attract those substances which are magnetic, and repel all others? We have strong grounds for believing this hypothesis to be true. No needle is ever magnetised without being subjected to the influence of this twofold current. For either it is magnetised by the current of the earth, which, as will be shown hereafter, is a double current, being at once positive and negative; or it is magnetised by being placed in a helix, through which an electric current is made to pass. Now an electric current, you are aware, is both positive and negative. It seems therefore impossible that the needle, being subjected to this double agency, should not have the corresponding effects produced in it, the more so because the substance of a magnet is composed, as we shall see, of two elements combined together, of which one is positive, and the other negative, and is on this account better fitted than most substances are to serve the purpose of transmitting a double current.

If the magnet, as has just been observed, attracts no substances but such as are magnetic, the simple reason of this is that we call those substances magnetic which have at the same time both an attraction of affinity to the substance of the magnet, and power to give effect to it by being able in such manner to adjust the position of the particles of which they are composed as to coincide with the direction of the current which plays around the magnet. All other substances, whether they possess an affinity to the substance of the magnet but are not capable of adapting themselves to the current flowing round it, or whether they possess magnetic properties of their own different from those of the common magnet, we call diamagnetic, because they exhibit a tendency to escape out of the confines of the ordinary magnetic field.

Again, if it is found that magnetic substances are attracted alike to both poles of the magnet, this after all is nothing more than that which takes place in the case of the insulated cylinder when it is inductively electrified. The same substances are attracted to the positive as to the negative end of the cylinder, although the current which predominates at each is of a different character. But, on the other hand, when a substance which is itself in an electric state is made to approach one of the ends of an inductively electrified cylinder, then they exert upon each other an attracting or propelling power according as their electricities are dissimilar or similar in character. In like manner, when the opposite poles of two magnets are brought together they attract, when the similar poles are made to approach they propel one another. There is therefore nothing in the manner in which the poles of the magnet act, either upon each other or upon other bodies, to prevent us from coming to the conclusion that one pole of the magnet is to be regarded as positive, the other as negative.

I have yet to answer another argument which is frequently brought forward by those who maintain that what we call the north pole of the magnet is in reality a south pole in relation to the north pole of the earth. Dissimilar poles attract one another. It follows from this, they say, that the magnetic pole of the earth which is situated in the northern hemisphere, and the pole of the magnetised needle which points to the north, must be dissimilar poles. Now although it is true the magnet points to the north pole of the earth, and the dip of the north end of the magnet goes on increasing as it approaches nearer and nearer to the north pole, until when it reaches the north pole it stands vertically over it, it does not follow that the north pole of the magnet is attracted to the north pole of the earth. When two parallel wires having a similar current passing along them are brought near to each other, they are attracted together; or, to speak more correctly, the two similar currents are attracted through the medium of each other to the negative elements in the direction of which they are flowing. Exactly the same thing occurs here. The magnetic current which circulates upon the upper surface of the earth, and that which circulates upon the lower side of the magnet, are two parallel currents. They both flow to their respective electrodes, and, by reason of their proximity the one to the other, are attracted together. This, however, does not prove that they are dissimilar currents, it proves the reverse. But, it is urged, when the magnet reaches the north pole, the north end of the magnet stands vertically over the north pole of the earth. We cannot, however, conclude anything from this, inasmuch as the same thing would undoubtedly happen whether the north pole of the earth exerted upon the north end of the magnet an attracting or a propelling force. The apparatus called the dipping needle indicates only the course of the magnetic current; in other words, it tells us not what is the character of the magnetic current which flows over it, but what is the direction in which it flows. The needle remaining fixed upon its axis, when it points vertically over the north pole, cannot, if attracted by the pole, approach nearer to it; if propelled by it, recede farther away from it. And if we succeeded in suspending the needle in such a way as to give it power to move freely either in the direction towards the earth or in the direction away from it, it would still be no easy matter to determine what magnetic influence was exerted upon it, because the operation of the law of gravity would have the effect of drawing the needle down to the earth even though the magnetic force should urge it in the opposite direction.

Yet if we cannot solve this problem experimentally, may we not with a high degree of probability determine how the magnet would act at the pole of the earth by ascertaining in what way two needles, one of which has been magnetised in the ordinary way, and the other in a manner similar to the earth, do act, under analogous circumstances, one upon the other? The difference between two such needles will be, as I have already pointed out, that whilst the same current flows in the case of both to the north pole, it will flow in the case of one round the needle from right to left, in the case of the other round the needle from left to right. It is easy to suggest a method by which two needles may be thus differently magnetised. Let one unmagnetised needle or bar be placed in the centre of one portion of a helix or coil of wire the convolutions of which run from right to left, and let the other be put in the centre of another portion of the same coil in which the convolutions turn in the opposite direction (Fig. 15), and then send an electric current through the coil. But simple though the method to be employed may be for effecting the object in view, I have not the means of trying it. I will therefore point out how two needles magnetised in the ordinary way act upon one another, and from the action which takes place between them infer in what respect the action of two needles magnetised in the manner I have described must differ.

The current circulates round the magnet from east to west on its lower side, and from west to east on its upper side. If then a small magnetic needle be suspended over a large and powerful magnet, the direction of the current on the lower side of the needle being opposite to that which flows on the upper side of the magnet, the needle, if free to move horizontally, will be carried round until its north pole points to the south pole of the magnet, or rather until it points a little to the east of the south pole of the magnet, when the two currents will flow on the contiguous sides of the magnet and the needle in a parallel direction. If the needle be at the same time free to move vertically as well as horizontally, it will place itself, not only in its declination but also in its inclination, parallel to the current circulating about the magnet. And in proportion as the needle is brought nearer to the north or to the south pole of the magnet the angle of its dip will increase, until when it actually reaches the pole it will stand vertically over it. Here, however, the two poles are dissimilar. Therefore they will be attracted together; for whenever, in the case of ordinary magnets, dissimilar poles are set the one facing the other, it will be found that the positive current flowing round each of them has the same direction in all respects, and that the two currents become virtually one current which flows over both from end to end.

Let us now turn to the case of two dissimilarly magnetised needles, and see wherein their action upon one another will differ from that of two similarly magnetised needles. If over a large magnet, with a current travelling on its upper side from east to west as it circulates towards the north pole, we suspend a small needle with a current travelling from east to west on its lower side as it proceeds to the north pole, it is manifest that the currents flow on the contiguous sides of the magnet and the needle in the same direction, and that the particular reason therefore which, in the case of the two similarly magnetised needles placed one over the other, caused the smaller one to reverse its position, and to turn its north pole in the direction of the south pole of the other, does not apply to our present case. Here, under the influence of like currents flowing in parallel lines on their contiguous sides, the magnet and the needle point their north pole in the same direction. And the nearer the needle is brought to the north end of the magnet the greater in proportion is the angle of the dip which it makes, until, when it reaches the north end of the magnet, it stands vertically over it. But, like currents issuing from the two poles, they will necessarily exert upon each other, not an attracting, but a propelling power. The propelling power which they exert upon each other will, however, be small compared with that which shows itself when two like poles of similarly magnetised needles are brought together; because, though we have current opposed to current in both cases, we have them opposed more directly in the one case than in the other. In the latter they meet in waves circling in opposite directions, *i.e.* one from right to left, the other from left to right; whereas in the former they meet in waves moving in the same direction, *i.e.* from right to left.

Now the relation between the earth and the magnet resembles, as I conceive, that which exists between two dissimilar magnets. The currents which flow upon the upper side of the earth and the lower side of the magnet are parallel. There is, therefore, attraction between them. The current which circulates to the north pole of the earth communicates itself to the magnet, circulating from one end of it to the other. It is, therefore, a like current which flows to the north pole of the needle. In this hemisphere the north pole of the magnet, by reason of the attraction which exists between the currents flowing upon the earth and the magnet, dips more and more as it approaches nearer to the north pole of the earth. When it reaches the north pole of the earth it will stand vertically over it (Fig. 16). The two poles will not be attracted together, because they are similar in character. On the other hand, they will not forcibly repel one another, because the currents which proceed from them are only indirectly opposed to each other. You may tell me this is not proof, it is only the statement of an opinion more or less well founded. I grant it; but from what has been said we are, I think, justified, until proof to the contrary is given, in holding the two following conclusions: first, that between the magnetic current of the north and that of the south pole of the earth, and also between the magnetic current of the north and that of the south pole of the magnet, there is a difference of character such as is usually expressed by the terms positive and negative. Of course, supposing this difference to exist in the former case, it must exist also in the latter, since the needle, though it does not always derive its magnetism in the first instance from the earth's current, is nevertheless indebted to it for the preservation of its magnetic character. The second conclusion which, it seems to me, we have a right to draw, is that the north pole of the earth and the north pole of the magnet agree together in the character of their magnetic current. When we know the character of the one, we know, therefore, the character of the other. What then, you may ask, is the character of the magnetic current at the north pole of the earth? Is it positive or negative? I assumed a little while ago that it was positive: I will give some reasons for believing it to be so.

Let an unmagnetised needle be placed within a helix or coil of wire which has its convolutions on the upper side turning from left to right, and let an electric current be sent in the same direction through the coil. The needle will become magnetised, and will have its poles turned in the same direction as those of the helix, and will be found similar to the ordinary magnet. Again, let a needle be suspended above the earth in the direction a dipping needle would assume, it will become magnetised by the earth's current. Let another needle be put in the plane of the magnetic meridian across a wire conductor; or, better, across a certain number of parallel wires, so situated that the current which passes along them will travel from east to west, with a slight inclination towards the north. As the positive current flows along the wires with a slight inclination towards the north, so it will circulate round the needle which is brought into contact with the wires in the same direction. We shall thus have a needle with a positive current flowing to its north pole, and it will be found upon examination to be in all respects similar to the needle magnetised by the earth's current. A somewhat analogous but altogether independent proof may be obtained in the following manner. Let a magnetic needle be suspended over a conducting wire which is placed in the magnetic meridian, and which has a current flowing along it from south to north. The needle will be deflected, its north end moving to the east so as to bring the current which flows on the lower side of the needle—which on that side flows from east to west with a slight inclination to the north—into parallelism with the current which flows along the wire. The deflection of the needle falls short of a right angle. It may be thought perhaps that the counteracting influence of the earth's magnetic current is the cause of this. But, however much the force of the current which flows along the wire be augmented, the deflection of the needle will never amount to a right angle, whereas if the positive current circulated upon the lower side of the needle from east to west with a slight inclination towards the south pole, its deflection ought to exceed instead of falling short of a right angle.* We are therefore, I think, justified in concluding that it is the positive current that flows to the north, the negative current to the south end of the magnet. And if so, from the similarity of the magnetism of the poles of the earth and of the poles of the magnet, we are justified in concluding that the north is the positive pole of the earth, and the south its negative pole.

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* See Deschanel's "Natural Philosophy," Part III. chap. xlvi.

LECTURE III.

MAGNETISM.

The nature and properties of the magnet—The relation between magnetism and electricity.

LET me proceed now to show the close relation which exists between magnetism and electricity, and endeavour to account for the differences which distinguish one from the other. They are like in many respects. They have both, as we have seen, a corresponding dualistic action. The one has its north and south pole, the other its positive and negative terminal. The electric current runs in a direct line from one terminal to the other; the magnetic current runs in an easterly and westerly direction round the needle from one pole to the other.* Both of them reside only or almost only on the surface of bodies. As regards electricity, we have had proof of this assertion already brought before us. Although the metals are good conductors, an electric charge communicated to an outer metallic sphere does not to any extent affect a smaller metallic sphere contained within the larger one. In a different manner, the same experiment may be applied to the case of magnetism Let a small iron cylinder, having another closely fitting iron cylinder inserted in it as a core, be magnetised. If the joint cylinders be thus taken together in one mass, or if the interior cylinder be removed and the exterior one be left alone, the surface exposed and the magnetic force will in both cases be the same. But if the core of the cylinder be drawn out so as to double the extent of the surface, the intensity of the magnetic force upon it will be found to be diminished by one-half.*

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* There is in reality a magnetic as well as an electric current running both ways, but when we speak of the direction of a current upon a conductor we take account, as a rule, of the positive current alone.

Again, magnetism and electricity both produce the same effects. A bar of iron may be magnetised either by means of a magnet, or by being placed within an electric coil through which a current is made to pass. The electric spark may be obtained either from the electric machine or from the natural or the artificial magnet. These are some amongst many points of similarity which are found to exist between magnetism and electricity. What are the points in which they differ? Magnetism has a much narrower field of operation. It is capable of being developed only in certain substances, which for this reason are called magnetic. Amongst these substances iron holds the most prominent place. Electricity, on the other hand, is capable of acting upon and of being developed in almost all substances in a greater or less degree; but then it has not the same permanent hold which magnetism has upon those substances in which it is developed. Again, a magnetic bar does not, like an electric ball, first attract a body which comes within the range of its influence, and then, when it has drawn it into contact with itself, begin to repel it. It continues always, so long as its influence remains undiminished and undisturbed, to attract it in the same manner. Further, when a magnetic bar is divided in two or more parts, each part is found to be a perfect magnet, having its two opposite poles; whereas an insulated cylinder, being divided whilst it remains under the influence of a charged ball, is found to have one section positively, the other section negatively excited. Lastly, the magnet has a tendency to rotate upon its axis.

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* Noad's " Student's Textbook of Electricity," p. 124.

The explanation of the causes of these differences which I have pointed out will throw considerable light upon what is the peculiar character of magnetic as compared with electric agency. Let me begin by calling to your mind the account which I have given of the action of the charged ball upon the insulated brass cylinder. The metallic substance of which the brass cylinder is formed consists of two elements, zinc and copper, the one being positive, the other negative, in relation to each other. The positive electricity of the charged ball, supposing it to be positively electrified, acts either directly or indirectly upon both these elements of the cylinder, but in a different manner. It excites the homogeneous (the zinc) element of the cylinder with an electricity similar to its own, viz. positive. It excites the heterogeneous (the copper) element with an electricity of the opposite kind, viz. negative. The cylinder being a conductor, the electric influence communicated to it makes itself at once felt from one end to the other. The copper element of the cylinder having an affinity to the excited zinc element of the charged ball, its energies, when once stimulated into activity, are directed to that end of the cylinder which is nearest the charged ball. The zinc element of the cylinder having no affinity to the homogeneous (zinc) element of the charged ball, its energies converge upon the other end of the cylinder, or upon that point, wherever it may be, which is nearest those bodies for which, as being negative in its regard, or having at any rate negative elements mixed up in their composition, it possesses an affinity. Were the electric forces which are here called into action powerful enough, the metallic substance would be decomposed, like the liquid in the galvanic trough, and its different elements borne different ways. If instead of the cylinder being made of brass—a metal composed of two elements, the one positive, the other negative—it were formed of one good conducting element, such as copper, we should still find it capable of transmitting the two currents, or, in other words, of discharging the double function performed by the compound metal, but it would not be able to do the work so effectually.

Now the magnet will be found in many respects similar to the insulated cylinder. It is composed of two elements. In the case of the natural magnet we have iron tempered by admixture with oxygen; in the case of the artificial magnet we have iron tempered by admixture with carbon. These two substances, viz. oxygen and carbon, are both of them negative and heterogeneous in relation to iron, and, under the circumstances, homogeneous in relation to one of the constituents of the air, viz. the oxygen. The magnetic current which flows upon the surface of the earth acts differently upon these different elements of which the magnet is composed. It acts upon the iron (the positive) element of the magnet, causing a current of positive electricity to flow towards one end of the magnet. When this current has reached the pole, not being able to pursue its course further, it exerts its energy upon the surrounding air, for the oxygen element of which it has an affinity. The earth's current acts also upon the oxygen or carbon, *i.e.* the negative element of the magnet, and causes a negative current to flow upon its surface in the contrary direction. When this negative current has reached the opposite pole, it discharges itself into the air, to the oxygen element of which it has the relation of homogeneity. As in the case of the charged cylinder the force of electrical attraction is greatest at the two ends, and a neutral line devoid of force is to be found in the space which intervenes between them, so the magnet exerts its greatest force in the vicinity of its poles, little or none in the centre, where the two opposite forces being equal neutralise one another's action.

These two currents upon the magnet of which I have spoken flow continuously around it, because the circuit is, in the case of the magnet, complete—it is different in the case of the insulated cylinder—and because, whatever loss of electricity takes place in different parts of the system, it is constantly repaired by an accession of fresh energy derived from the magnetic current of the earth. As in the case of the insulated cylinder, so it is found in the case of the magnet, that though a rod which consists of one element alone may, if that element be a good conductor, be able to transmit both the positive and negative currents, it cannot do the work so effectually as a rod which consists of two different elements. Thus, *e.g.*, a bar of iron in its pure and soft state possesses in itself the properties of the magnet, so long as it remains within the range and under the influence of magnetic forces. Being surrounded by the coils of an insulated wire, along which an electric current is made to pass, it exhibits these properties in a higher degree than any natural or artificial magnet. But the moment the electric current is stopped it loses these properties altogether. On the other hand, a bar of hard cast-iron, having a very small admixture in it of carbon, is capable of being permanently magnetised, although it exhibits very little magnetic power; whilst a bar of steel, which has a larger admixture of carbon, is capable not only of being permanently magnetised, but of being magnetised to a higher degree. In order then that iron may be made capable of retaining the magnetic character, it is necessary that it should be combined with oxygen or carbon, or some other element which has an affinity to one of the constituents of the air. The iron loses thereby some portion of its power as a conductor of electricity, but what it loses in conductivity, it gains in statical and inductive force. It is thereby enabled to diffuse its magnetic influence through the space around it which is called the magnetic field. This circumjacent expansion of magnetic force may be made apparent by putting a sheet of white paper or a thin plate of glass over a magnetised bar, and then sifting fine iron filings upon it. On gently tapping the paper or plate, the particles of iron will be seen to arrange themselves round about the bar, forming a succession of curves known as the curved lines of magnetic force (Fig. 12).

Now the same effect which is exhibited in so striking a manner when we put a sheet of paper over the magnet and sprinkle iron filings upon it is, we have a right to infer, produced in like manner, although not in the same degree, in the atmosphere surrounding the magnet, because one of the constituents of the atmosphere, viz. the oxygen, resembles the iron filings in so far as it is a magnetic element. Evidence is not wanting in proof of this assertion. Let me cite one out of many experiments which might be quoted as showing the effect produced by the magnet upon the air which surrounds and lies between its two poles. Let a small cube of copper—this metal is a good conductor of electricity—be suspended between the poles of a powerful horseshoe electro-magnet. If the cube be made to rotate rapidly by means of a twist given to the thread from which it hangs, it will suddenly be brought to a stand when a current is made to pass through the coils of the electro-magnet, and it will begin again to rotate as soon as the current is turned off. Should the tube be forced, however, to turn round against the resistance it meets with in the air, its temperature will be raised in a sensible degree (Fig. 17).

The magnet, as has been said, acts upon the oxygen element of the air, and the cube of copper, the substance of which has a strong affinity for oxygen, being surrounded on all sides by the air in an electric state, is held fast by the force of the attraction exerted upon it. It is, moreover, highly probable that the magnet when powerfully excited acts upon the ethereal medium which pervades the solid body. It is the peculiarity of magnetic action that it should be transmitted with ease through all bodies which are not decidedly magnetic. An instance of this kind has been brought before us in the case of the magnet acting through the sheet of paper or plate of glass interposed between itself and the iron filings. If what I have said be true, it is more easy to understand how the magnet should be able thus suddenly to arrest the movement of the copper cube by acting upon the particles within as well as upon those that are without.

From the inspection of the diagram representing the magnetic field, we learn another important fact, viz. that one pole of the magnet acts upon the other through the surrounding air. The current circulates upon the bar east and west, and a certain portion of it travels back from one pole to the other by means of the magnetised air, and so recommences its course along the surface of the bar, whilst another portion of it escapes at the ends of the magnet into the air, and is dissipated and lost.*

In order then that the magnet may be able to retain permanently its power, it is necessary that this continual loss which is going on should be in some way made good. If the magnet be a straight bar, it should be left, if possible, to take up a position corresponding to the direction of the magnetic current of the earth. If it be curved in the form of a horseshoe, it should be provided with an armature or keeper (Fig. 13). In the former case, whatever may be the amount of force dissipated at the poles, the magnet will be able to take up from the earth's current the supply which it needs in compensation. In the latter case there will be a certain waste going on in the system, though not to the same extent as in the former case. The magnet, however, having its circuit completed by the armature, will always, in whatever position it may be, coincide in some part with the direction of the earth's current, and thus obtain what it needs to repair its loss.

We have here, then, another characteristic feature which belongs to magnetism brought out to view. Other electricities are derived from different substances acting mutually one upon another. Magnetism is the result of the electric current of the earth exerting its influence upon such substances as have an affinity to it and are capable of an electric action similar to its own. It is important to note that the current which polarises the magnetic bar polarises the individual particles of the surface of the bar, if not the individual particles of the whole mass. As far as it is in their power to move, they arrange themselves like so many small magnets connected together, having their longest dimension turned the same way as the magnet of which they form a part. This effect is made visible in the case of the iron filings or small magnets placed on a sheet of glass, or of white paper, over a large and powerful magnet. They attach themselves end to end, and arrange themselves along what are called the lines of force in the magnetic field; in other words, they are polarised by the electric current which passes to them from the magnet, and circulates around them also. We have a still more striking manifestation of the same effect presented to us when a glass vessel, filled with water, containing in it the oxide of iron in a state of powder, and wound round by a coil of wire, is magnetised by an electric current being sent through the insulated wire. A lighted candle looked at through the liquid before the circuit is closed appears dim, but the moment the electric current is made to pass it shines clearly, because the particles of oxide suspended in the water when magnetised arrange themselves, like the iron filings, in lines, and offer little obstruction to the passage of the rays of light. The movement of the particles of the iron bar of which I have just spoken, when effected by the agency of a powerful electro-magnet, is accompanied by a distinct sound, or magnetic tick, and the bar itself is in a very minute degree lengthened. This tick is again heard, and the bar contracts to its former dimensions, when the electric current is broken, and the particles fall back to their first position.

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* Faraday tells us that the existence of this magnetic field, completing the circuit between the two poles, is absolutely and indispensably necessary for the preservation of magnetic force. He found that, when the magnetic area of one magnet was encroached upon by the conflicting influence of another, the force of the weaker magnet was diminished, and in some cases quite overcome, its poles being reversed.

From the inspection of the diagram representing the magnetic field, we also learn why it is that the magnet, besides having its north and south polarity—which is due to the fact of the current flowing round it east and west from one end to the other—has also an inclination, or dip, which increases as it approaches nearer to the poles, until when it reaches either one of the poles it has a vertical position. The earth, as I shall endeavour later to show, is a great magnet. The space lying between the centre and the pole of one hemisphere communicates magnetically through the surrounding atmosphere with the space lying between the centre and the pole of the other hemisphere. Within these limits the magnet everywhere, if free to move, arranges itself along the line of force which connects any point in the one hemisphere with its corresponding point in the other. Outside of these limits the magnet sets itself vertically in the direction in which the magnetic force passes away from the pole into the surrounding air.

We may now turn to the explanation of the causes of those differences which I have noted as existing between magnetism and electricity. In the first place, it will be easily understood from what has been said why the hold which magnetism has upon those bodies in which it is developed is so much more permanent in its character than that which electricity has. The air surrounding the magnet becomes itself magnetised, and when the current which travels round the surface of the magnet has reached one of its poles it returns, in the same circuitous manner, through the magnetised air to the other pole, there to begin its course again. There is a certain expenditure of magnetic force in the passage of the current along the surface of the magnet, and a considerable waste at the ends of the magnet, but the current of the earth by its action upon the magnet makes good whatever loss is in this manner sustained.

It is in the next place easily seen why the magnet, after drawing a body into contact with itself, and communicating to it a share of its own electrical energy, does not, like a charged ball, propel the body from it. Two bodies drawn together by electrical attraction form electrically one body, and act upon other bodies around as one body. Nevertheless, when one of these two bodies thus drawn together happens to be nearer than the other is to a third body to which they both have an affinity, and when this body which is nearer, and consequently concentrates upon itself a greater amount of electric force, is at the same time less affected by the law of gravitation, as in the case of a pith ball joined to a brass ball, it is not difficult to understand how such bodies brought together by attraction may be parted from one another once more by attraction, the lighter body being carried forward in advance of the other in the direction of the attracting object. But the case is different with the magnet and the body attracted to it. The current does not flow upon the magnet in a direct line, or exert a propelling power, it circulates round the magnet, and round the body which it magnetises, the two poles exerting an attraction upon one another through the medium of the air. Hence a body once attracted to a magnet does not fall off from it so long as the action of the magnet is not diverted elsewhere, or diminished to such an extent that the force of gravity is able to overcome the force of magnetic attraction, in which case the body would of course fall to the ground.

Again, the reason is evident why it is that a magnet being divided into two parts each part is found to be a perfect magnet, having at each end opposite poles; whereas, if an insulated cylinder made up of two sections be parted asunder in presence of a charged body, each section will be found differently excited, the one positively, the other negatively. All the particles of which the surface of the magnet is formed are, as has been explained, themselves magnetised, having each a north and south pole pointing in the same direction as the larger magnet of which they form part. Wherever then the division of the magnet is made, the ends of each section will be marked by an electricity of a different character, and the circuit between the two ends of each section will be made good through the medium of the magnetised air.

Lastly, we see why the magnet has a tendency to rotate upon its axis, whereas the insulated cylinder under the influence of electrical excitement shows no such tendency. The reason of this is because the current upon the cylinder passes along it from end to end in a direct line; the current upon the magnet, on the other hand, circulates upon it from one end to the other, and that portion of its current which is absorbed into the air retains a rotatory motion. Hence we find that electro-magnetic rotations follow when we cause electric and magnetic currents to act one upon another. Let (Fig. 19) the wire conductor of an electric battery be divided, the electric connection between the two parts being maintained by the vessel into which their ends are made to dip being filled with mercury or some other conducting liquid. Place a magnet in the pathway along which the electric current flows, one end of the wire being attached by a non-conducting thread to the magnet, whilst the other end of the wire reaches into the curved lines of force which surround the magnet. The circuit being closed, if the two ends of the wire are fixed, and one end of the magnet is free, the end of the magnet which is free will begin to rotate round the wire (Fig. 19). If the two ends of the magnet are fixed, and one end of the wire is free, the end of the wire which is free will rotate round the magnet. If both ends of the magnet are free, under certain conditions the magnet can be made to rotate upon its axis under the influence of the electric current.

Ampère effected the rotation of the magnet upon its axis in the following manner.* He loaded one end of the magnet with platinum, so as to be able to float it in an upright position in a vessel filled with mercury (Fig. 18). He formed a cavity in the upper end of the magnet—which stood out of the liquid in the vessel—and poured mercury into it. On connecting one of the terminals of an electric battery with the mercury in the hollow of the floating magnet, and the other terminal with the outer edge of the mercury in the vessel, the magnet began at once to rotate. This result is due to the action which takes place between the outflowing current from the magnet, and the circulating current upon the magnet, and is strictly in accordance with the electro-dynamic laws. The outward-flowing current CD (Fig. 18^1), attracts the current C*m*, since both proceed from the same angular point, and propels the current *n*C. Hence the magnet is made to rotate in the direction *m*C*n*, i.e. in the direction in which the negative current circulates upon the magnet.

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* Deschanel's "Natural Philosophy," Part III. chap. xlviii.

The other rotations may be explained in like manner. I will take the first of the instances given above. We have (Fig. 19) an electric current passing through the mercury in a direct line from one terminal to the other, and intersecting at a certain angle the magnetic current. We have a magnetic current circulating upon the upper surface of the magnet from west to east, *n*C*m*. According to one of the electro-dynamic laws, "*currents whose directions are inclined to each other at any angle attract each other if they both flow towards the vertex of the angle, or if they both flow from it; they repel each other if one of them flows towards the angle and the other flows from it.*" In this case CD, the outflowing current, attracts C*m*, because both flow from the angular point C, and repels the current C*m*. Hence the magnet, if free to do so, would rotate on its axis in the direction *m*C*n*. It is prevented from rotating by the fact of its lower end being fastened; therefore the upper end of the magnet moves round the wire in that direction in which it would under the circumstances rotate if free to do so, viz. in the direction of its negative current. It would be easy to go through the explanation of the other rotations, but the explanation of this one is sufficient.

LECTURE IV.

DIAMAGNETISM.

All bodies divide themselves into two classes, magnetic and diamagnetic—In what way the action of the one differs from that of the other—What cause can be assigned for this difference.

THERE is one particular branch of the subject I am treating which I confess I scarcely know how to deal with, but which I am prevented from passing over altogether in silence because it is in some sort necessary, in forming a judgment concerning the nature of magnetism, that it should be taken into account.

It used to be supposed that all substances, so far as they are amenable to magnetic influence, are affected by it in the same way. Faraday showed that the magnet acts in a different way upon different substances. He divided all substances into two distinct classes: those belonging to one class he calls paramagnetic, because when subjected to magnetic influence they act like the magnet; those belonging to the other class he calls diamagnetic, because when subjected to the same influence they act in a contrary way. If, *e g.*, a slender rod of iron be suspended between the poles of an electro-magnet, it will be attracted by them, and will take up a position on the line connecting the two poles, or, as it is said, it will place itself axially between them (Fig. 20). If a rod of bismuth, which may be taken as an example of a diamagnetic substance, be suspended between the poles of the magnet, it will appear to be repelled by them, and will take up a position across the line joining the two poles, or, as it is said, it will place itself equatorially between them. In point of fact, the number of substances belonging to the diamagnetic class is far greater than the number belonging to the magnetic class; but, on the other hand, the force of magnetism is very much greater than that of diamagnetism. To what are we to ascribe this difference which is found to exist between magnetic and diamagnetic bodies? It is plain that the nature of the medium in which the body is suspended must be taken into account in judging of the result brought about.

Some bodies place themselves axially between the poles of a magnet in one medium, equatorially in another. The air itself is magnetic by reason of its oxygen element. It is easy to understand, therefore, how any substance which has less attraction to the magnetic body than the air would be displaced by it. Nevertheless, it would be wrong to infer from this that there is no such thing as diamagnetism *per se;* that bodies are diamagnetic only when they are placed in a medium of greater magnetic power than their own. For there are substances which exhibit diamagnetic effects as decidedly in a vacuum as in any medium. Bismuth, *e.g.*, is always found to set itself equatorially between the poles of an electro-magnet, in whatever medium it may be tried. It follows the same law of induction which applies to magnetic bodies, being attracted by a force which is proportionate to the square of the strength of the inducing body. It behaves, in fact, whilst under magnetic influence in all respects like a magnet, except that it has a different polarity. To what then is this difference of polarity owing? The position assumed by a bar under magnetic influence will depend upon the manner in which the current passes over it. When a slender rod of iron is suspended between the poles of an electro-magnet, it places itself, as I have said, axially between them. This is because the particles upon the surface of the iron rod have the power to adjust their position to the circular movement of the current flowing from one pole of the electro-magnet to the other. The iron rod and the electro-magnet, taken together, may be compared to a bar having consecutive poles. The current passes over the electro-magnet, and over the rod from end to end, in the same direction, whilst the several poles are connected together through the medium of the air. But with a rod of bismuth, which is a highly crystalline substance, the case is different. In traversing a crystal the current takes the direction of its magnetic axes. But as the laminæ which lie on the surface of the bismuth dip beneath it, they cannot, like the particles upon the surface of the iron rod, shift their position and fall in with the direction in which the current flows over them. Hence the rod is forced to swing itself round. From what has been already stated—viz. that the bismuth rod acts like a magnet as long as it has an electric current passing over it—it seems to follow that it must have a magnetic field of its own. It is not therefore surprising that, whilst it is in an electric state suspended equatorially between the poles of the electro-magnet, it should, if brought near to either pole, be repelled from it. What has here been said concerning the action which takes place between the magnet and bismuth, applies generally to the action of the magnet upon the metals, and other substances of a crystalline structure which belong to the diamagnetic class. But included in the same diamagnetic class there are to be found other substances, such as wood, ivory, glass, leather, which are either not of a crystalline structure, or are not conductors of electricity, and, having no magnetic field created about them, have no polarity. Can it be explained why these substances, when suspended between the poles of the magnet, put themselves transverse to the magnetic current? The magnet transmits its influence through all substances which are not magnetic, and we have reason to think that it does so in consequence of its readily acting upon the ethereal medium by which even solid bodies are permeated. It seems natural, then, that under the influence of a powerful electro-magnet these bodies should be acted upon mechanically by this interpenetrating medium, and be made to assume that position which offers the smallest resistance to the passage of the current through their interstices. Thus a piece of wood, or a square of glass, moves round until they oppose their narrowest breadth to the current. It is, however, only when the most powerful electro-magnets are used that neutral substances are in any way affected by the current.

I have represented the current which passes between the two poles of the electro-magnet as having a circulating or rotatory motion. The current circulates round the magnet from one end to the other, and there seems no reason for doubting that it retains the same motion in passing from one pole to the other. Well then, as the rotation of the current upon the magnet accounts, as it seems to me, for the rotation about it of an electric current which is brought within the range of its influence, when the magnet is fixed and the current is free to move; so, in like manner, if we admit the rotation of the current between the poles of the magnet, that rotation may suffice to account for the rotation which takes place of a polarised ray of light which is made to pass through a cube of heavy glass placed within the field of the magnetic force.* It is not, however, necessary for me to pursue this subject any further.

* Sir W. Harris's "Rudimentary Magnetism," p. 78.

LECTURE V.

THE EARTH A GREAT MAGNET.

The earth has the conditions and characteristics of a magnet—Its continuous current—Its combination of current and statical electrical action—Its polarity—Its magnetising power—Its tendency to rotate upon its axis.

FROM what has been said concerning the nature and properties of a magnet, it follows that the earth is a magnet; or perhaps it would be more correct to call it an electro-magnet, *i.e.* a body which is not in itself permanently magnetic, but which, so long as it has an electric current flowing round it, acts like a magnet. In the first place, for the permanency of its electric condition it is necessary that the magnet or electro-magnet should have a current continually flowing over it. The earth has an electric current at all times flowing upon its surface. Careful observations have been made, and magnetic charts have been drawn up showing by the inclination and declination of the needle what is the direction in which the current flows in different parts of the earth, and what is its varying intensity. Barlow wrapped coils of wire round a wooden globe so as to imitate the magnetic parallels and poles of the earth. He then caused a galvanic current to pass through the wire from east to west. Carrying a small needle over different parts of this globe, he found its declination and dip bore a striking resemblance to those of a needle similarly situated on the surface of the earth. From the magnetic equator, where the needle rests horizontally, the angle of inclination continues to increase as we approach towards the magnetic pole, where the needle will stand vertically or nearly so. It is strictly in accordance with the known laws of electro-dynamics that the current upon the magnet should thus place itself in parallelism with the current upon the surface of the earth (Fig. 16).

It is another characteristic of the magnet to combine together the action of current and statical electricity. The earth does the same. If we are bound to admit that it is a conductor of electricity, inasmuch as it has everywhere a current flowing over its surface, it is beyond all question an extremely bad conductor. The electricity which is unintermittingly raining down over that half of the globe upon which the sun shines is, before it has proceeded far along its course, either absorbed beneath the earth's surface, or taken up by the atmosphere revolving in the opposite direction; only a small residuary portion continues to flow on in a stream, which, if it were not constantly fed by a fresh supply, would quickly be dried up and be lost. As will be shown later, the sun is in a positive electric state. It moves in relation to us from east to west. Hence the positive electric current, which arises from the action of the sun upon the electro-positive elements of the earth's surface, flows in the same direction, viz. from east to west; whereas the negative electric current, which is generated in the electro-negative elements upon the earth's surface, flows in the opposite direction, *i.e.* in the direction towards the sun from west to east.

These two currents will continue their course to their respective poles in so far as they are not prevented from doing so by the imperfect conducting power of the earth, and the other causes I have named. The development of an electric state of a different kind in the air and in the clouds floating therein cannot but affect the current upon the earth, and give rise to local perturbations of a more or less important character; and the fact of the almost daily recurrence in the polar regions of the aurora borealis and australis, which are admitted to be of magnetic origin, is at once a proof that the magnetic current reaches to the highest latitudes, and that the earth, like the magnet, extends its influence into the air to a certain distance around, which may be called its magnetic field, and also that this influence is in the case of the earth, just as in the case of the magnet, greatest at the poles and weakest at the centre between them; in other words, at the equator. This last-mentioned fact admits of stronger and more decisive proof. A needle made to vibrate near to a magnet is brought so much sooner to rest as the force of the magnet is greater. It makes fewer oscillations when made to vibrate near one of the poles, a greater number of oscillations when made to vibrate at the centre. Precisely the same thing happens to the needle in relation to the earth. The difference in the number of oscillations which the needle makes when its equilibrium is disturbed at different parts of the earth shows that the magnetic intensity of the earth is least at the equator, and increases as we proceed from the equator either towards the north or the south pole. But in consequence of the earth being, as I have said, a very imperfect conductor, the difference of the magnetic force which displays itself at the equator and at the poles of the earth is very small in proportion to the difference which manifests itself at the centre and at the poles of the magnet.

Next, the earth has, like the magnet, its opposite poles. This is a fact admitted by all. But when we proceed to inquire into what is the precise nature of the polarity of the earth, we find a great diversity of opinion prevails on this subject. Some affirm that there are two magnetic poles in each hemisphere. Halley and Hansteen agreed in this conclusion, though differing from each other in a point of importance which it is unnecessary to dwell upon here. The common opinion, however, is that there is only one pole in each hemisphere. Gauss maintained this opinion, but in place of a single determinate pole he substituted the idea of a magnetic polar region in each hemisphere, and held that the irregularly diffused magnetic elements of the earth have collectively a resemblance to the condition of a common magnet. According to another opinion, differing perhaps more in appearance than in reality from the last mentioned, every place has its own magnetic pole; or, in other words, the magnet everywhere points to the north except so far as it is turned aside by local or other magnetic influences. This last opinion best accords with that which I hold to be the true theory of terrestrial magnetism, which maintains that the currents which circulate upon the earth owe their origin to the electric power of the sun. The fact that these currents flow upon the earth in an easterly and westerly direction accounts for the existence of a north and south magnetic pole; and the fact that these currents, being communicated from the earth to the magnet, flow upon its lower side in an easterly and westerly direction explains why the magnet, without having any sensible attraction to the poles of the earth, should nevertheless point in the direction of them.

It is to be observed the magnetic poles of the earth do not coincide with its geographical poles. What is the reason of this? The axis of the earth, as you are aware, is not perpendicular to the plane of the ecliptic or sun's path in the heavens, but has an inclination out of the perpendicular of about twenty-three and a half degrees. The consequence is that, the geographical poles continuing always to point in the same direction whilst the earth performs its circuit round the sun, the magnetic poles move from twenty-three and a half degrees north to twenty-three and a half degrees south of the geographical poles. In the next place the magnetic and geographical meridians of the same place do not, as a rule, coincide one with the other. I have said that the positive current circulates round the earth from east to west, with a slight inclination to the north. We should naturally expect, therefore, to find the magnetic pole situated somewhat to the east of the geographical pole. This anticipation, however, is not borne out by the fact. At London, *e.g.*, at the present time—for there is a certain periodicity of change which takes place in the magnetic elements—the needle, instead of pointing some degrees to the east, points twenty degrees to the west of the geographical pole. What is the cause of this deviation of the needle from what may be called its due magnetic north? The answer is because the needle is turned aside by local and by other magnetic influences. I shall be better understood, however, if I take up the explanation of this point later. I will go on at present with what I have to say in the way of proof of the earth's magnetic character.

A magnet has the power of magnetising other bodies which have a capacity for receiving this permanent form of electricity. The earth possesses this power. If a steel rod be kept for some time in a position parallel to that of the dipping needle it will become magnetic. Again, a bar of soft iron held in the same position will be magnetised in a still more powerful degree, though only temporarily. For this reason also masses of iron cannot remain stationary on the surface of the earth for any length of time without exhibiting signs of magnetisation. And the magnetism of the loadstone is attributed to the same cause, viz. the influence of the magnetic currents of the earth. Lastly, we are told, a magnet has a tendency to rotate upon its axis. This has been proved theoretically by Ampère, and demonstrated experimentally both by Ampère and by Faraday. The earth also rotates upon its axis. The magnetic current flows upon the earth from east to west, whilst the rotation of the earth is from west to east. I shall endeavour to show later how these two different effects proceed from the sun's electric action upon the earth.*

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* In a lecture like the present it is difficult to convey one's meaning without having recourse to popular language, and difficult to use popular language without incurring the risk of conveying false notions, unless the meaning in which certain words are used be accurately stated. The terms east and west point out not absolutely but relatively different parts of the heavens. We call that direction east in which the sun rises to us, that direction west in which the sun sets in regard to us. When I say the magnetic current circulates upon the earth from east to west, I mean that it flows from east to west on the side of the earth which is turned to the sun. It must therefore, in relation to us, flow from west to east on the side of the earth which is turned away from the sun.

LECTURE VI.

SUN AND EARTH IN A CORRESPONDING ELECTRIC STATE —INTERPLANETARY MEDIUM.

The theory which derives the magnetic character of the earth from the electric action of the sun is in harmony with observed facts—The existence of a highly attenuated medium between them.

LET me begin with observing that we have the authority of Herschel for regarding the sun as an immense globe, in a permanent highly electrified state. He must be understood to mean that the condition in which the sun is is one of positive electricity. Now, as you are aware, a body charged with electricity, acting upon another body separated from it, throws that body if it rotates, or the side of that body which is opposed to it if it is stationary, into an electric state which is the reverse of its own. On the supposition then that the earth's electric condition is due to the action of the sun, we should expect to find the earth in a negative state of electricity. Now, in point of fact, whatever the cause may be, we do find the earth to be in a negative electric state. This was shown by Volta, who, by catching the fine spray of a fountain on the plate of a straw electroscope, found the straws to diverge with the negative electricity communicated to them by the water, which was necessarily of the same character as that of the ground. I will refer next to an ingenious experiment made by Becquerel on the plateau of Mount St. Bernard, establishing the fact that the earth is in a negative state in relation to the upper regions of the air. Having connected the shaft of an arrow by means of a conducting string with an electroscope, he first shot the arrow in a direction level with the ground, next, vertically in the air. In the first case the electroscope showed no change; in the second, the higher the arrow was shot, the greater was the degree of positive electricity which was indicated. That an opposition exists between the electric condition of the earth, and that of the upper regions of the air and of the clouds floating therein, admits of no doubt. When the antagonism between these two electricities,* the one positive, the other negative, reaches to a certain degree of intensity, they burst through the intervening barrier of the non-conducting air, and cause the thunder-storm which breaks over our head, the tornado which raises up the waters of the sea, or the sands of the desert, and other not less striking phenomena.

Peltier, and some others, explain the positive electrical state of the upper atmospheric strata as an effect of induction, caused by the negative state of the earth—the negative state of the earth itself being left unaccounted for. If, however, it can be shown that the sun is the primary source of electric power, we account for the electric state of both. The earth acquires its electric character, by induction, from the sun through the network of the ethereal medium reaching from one to the other. The air derives its electricity, or at all events the greater part of that which it possesses, by induction, or in some other way, from the earth. I say by induction, or in some other way, because it may be that the electricity of the upper atmospheric strata is obtained from the earth, in part by induction and in part by convection. We know that when the prime conductor of the electric machine is charged, the air carries off some portion of the electric fluid; and the more highly the conductor is charged, the more in proportion does the air abstract of its electricity. In like manner, then, the air which is in contact with the earth must become in some degree impregnated with its electricity. But, as a rule, the air thus brought in contact with the surface of the earth becomes raised in temperature, and will therefore mount upwards, bearing the burthen of its electricity along with it. You may tell me that the earth is negatively electrified, and that the electricity which the air carries away must therefore be negative electricity. Well, at times it is found that not only the lower strata of the air but the higher also are negative; more especially is this the case in damp weather, when the earth more freely parts with its own electricity. But you must bear in mind that, though the electric character of the earth itself is negative, it has a current of positive electricity flowing over its surface from east to west, and that the air which is in contact with the earth rotates with the earth in the opposite direction, and cannot fail to take up some portion of this positive current. Hence, in all dry weather, when the earth does not so easily give out its own electricity, it is found that positive electricity predominates in the upper regions of the air.

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* I use the word antagonism not in the sense of these two electricities being themselves opposed to one another, but because of the conflict amongst the elements they give rise to.

Heat, in the way in which it is communicated to the upper strata of the air, furnishes a case exactly parallel to that of electricity. The earth receives its heat direct from the sun; the air receives its heat principally from the earth. The temperature of the upper regions of the air is much lower than that of the earth, although the rays of the sun must all pass through it before they can reach the earth. But then the air, being well-nigh transparent to the solar rays, absorbs but a very small portion of them. Its heat is derived partly from the lower strata of the air ascending up when it has been heated by contact with the earth, partly from the presence in the air of aqueous vapours, which intercept the heat of lower temperature which is radiated from the earth. We are not without proof that a difference exists between the nature of the heat which comes from the sun, and the nature of the heat which proceeds from other sources. The glass of our windows is transparent to the solar heat, but opaque to the dark heat radiating from the fire in our room. To some extent, no doubt, the air must be affected by the direct action of the sun. Now, as the air intercepts a certain portion of the sun's heat, so in like manner will it intercept a certain portion of its electrical influence. It is to be observed, however, that the electricity thus directly communicated to the air by the sun will be of the same positive character in relation to the earth as that which it derives from the earth by induction.

From what has been said you will have perceived that I hold that matter, in some condition, however attenuated it may be, exists through all space, and in such continuity that forces may be developed and transmitted by and through this medium. The existence of an interplanetary and interstellar medium I consider to be demonstrable upon other besides physical grounds. But as my argument in proof of the electrical action of the sun upon the earth necessarily supposes the existence of such a medium, and as there are some who call it in question, I wish to say a few words upon the subject before passing on to other considerations.

First, then, all who accept the theory which is most generally held at the present day concerning the nature of light and heat, viz. that they are a mode of molecular motion, seem bound in consistency to hold that there are molecules or atoms transmitting this motion from the sun to the earth. Again, in regard to gravitation, if you say that the tides of the ocean are raised, the perturbations of the planets produced, without any intervening medium between the bodies affected and those affecting them, you quit the domain of physics altogether, you put an abrupt end to all inquiry, to all reasoning on these questions.* When you thus separate the parts of creation one from another by the intervention of spaces where nothing exists, where secondary causes are precluded from acting, you make God Himself act immediately. Now to bring in the immediate agency of God to supply for the absence of what is supposed to be wanting in nature, in order to combine the action of the different parts of the universe in one harmonious whole, is to break up the idea of a work of design and of perfection. Neither can you validly infer from the ascertained action of physical causes what will be the action of God where no physical causes exist. The continual shortening of the path of Encke's comet has with great plausibility been adduced as evidence in favour of the existence of a material medium pervading space. It has, indeed, been urged on the other side that the existence of such a medium would retard the motion of the planets in their course round the sun. But it is not unreasonable to suppose that this medium, as being an emanation from the denser bodies of our system, should participate in the general movement which belongs to them, in which case its motion would correspond with that of the planets at their respective distances from the sun, but would necessarily have the effect of impeding the advance of a body like a comet, extremely rare in its substance and moving with great velocity in a contrary direction.

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* "Essays," by Sir H. Holland.

One thing, I observe, Mr. Janssen considers as placed beyond doubt by the investigations into the phenomena accompanying the eclipse of the sun, viz. the existence of a medium extending outside the photosphere of the sun and made manifest to an immense distance by its luminosity. As to the fact of some material substance pervading interstellar space, Newton expresses himself very strongly. "To suppose," he says, "that one body may act upon another at a distance through a vacuum, without the mediation of anything else by and through which their action and force may be conveyed from one to the other, is to me so great an absurdity that I believe that no man that has in philosophical matters a competent faculty of thinking can ever fall into it."*

I need not dwell longer on the proof of there being a connecting medium between the sun and its attendant planets. I proceed next to show that this medium serves as a conductor for the transmission of the chemical and electrical influence of the sun to the earth, and enter upon the direct proof that the earth derives its magnetic character from the sun.

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* It has been maintained that where there is no empty space no movement is possible. There can, however, be no difficulty about the possibility of a body moving in the air or in the water if the place occupied in the first instance by the solid body be left for the fluid body which is displaced to pass into it. This movement, which is in all such cases feasible, must be admitted to be, according to the theory most commonly held, very greatly facilitated in consequence of the air and the water moving in a medium as much more rare and elastic compared with themselves as they are in comparison with solid bodies. I speak of that impalpable ether which fills up the interstices between the contiguous particles of the air, which is diffused throughout space, and, as an all-embracing network, incloses and binds together all the parts of the universe. I do not, however, deny that between the particles of whatever may be the most rarefied medium there are empty interstices. To account for the action of bodies one upon another it is sufficient they should come into contact at certain points, it is not necessary they should touch on every side.

LECTURE VII.

THE SUN AN ELECTRIC AGENT.

The proof of the sun exerting a chemical action upon the earth implies its possessing an electric influence—Direct proof of its exercising an electric influence.

IF we decompose a ray of solar light by passing it through a refracting prism, we shall find that it is made up of three distinct elements, light, heat, and actinism, or chemical force. The rays of light have a mean refrangibility; they lie wholly within the spectrum. The heat rays are the least refrangible, lying partly within the spectrum blended with the red, partly without the spectrum extending beyond the red. The chemical rays are, of all, the most refrangible. They are on the other side of the spectrum, being situated partly within it blended with the indigo and violet rays, partly without extending beyond the violet. Hence it follows that the rays of the sun wherever they fall—and they are falling continually over more than one-half of the globe—carry along with them a chemical power which they exert as far as circumstances permit. Do you ask for any proof of this? The light of the sun tarnishes silver; and it is in consequence of this chemical change which the sun's light produces on a preparation of silver that the photographer is able to gratify you with a speaking likeness of yourself. The light of the sun will in like manner tarnish your complexion if it be exposed to the action of its scorching rays. This is not the mere effect of heat: you may live in the tropics without putting on the livery of the sun, if you do not go into his presence. It is this same chemical power of the rays of the sun which clothes the landscape in the spring in a robe of light green, and as the months pass on mellows that bright tint into the sombre and variegated hues of autumn. Other examples without number might be given of changes produced on the earth by the chemical action of the sun's rays, but more are not required. In briefly explaining the facts which I have here given, let me remind you of what takes place in the liquid of the galvanic trough when the circuit is closed. The oxygen element combines with the zinc, for which it has an affinity. The hydrogen element set free on the surface of the opposite plate does not combine with the copper, not having any affinity to it, but transmits a current to the oxygen element on the surface of the zinc plate, with which it is brought into connection by means of the conducting copper wire. In the same manner, in the daytime, under the influence of the sun's chemical rays, the sap in the leaf of the tree has its negative element excited, and thus attracts to itself the carbon which, in the form of carbonic acid, is diffused in the atmosphere around. It absorbs, in fact, more than it is able permanently to retain, and when the sun's light is withdrawn it gives out a portion of that carbon which it had absorbed during the day. Upon the same principle, *i.e.* by means of the attraction and the absorption of the carbonic acid in the air, it is in our power to explain the effect which the sun has in discolouring our complexion, and in darkening the negative plate of the photographer when exposed to its rays.

Now if it be admitted that the sun's rays are endowed with chemical power, it cannot be doubted that they are capable of producing electrical and magnetic effects, which are in reality nothing more than chemical effects exhibited in a limited and modified form. As the positive element in the galvanic trough is able to transmit a current to the negative element by means of the conducting wire which brings them into communication with each other, so the influence exerted by the chemical rays of the sun, being communicated in every part of the earth to substances which are conducting, as well as to substances which are non-conducting, must everywhere give rise to currents, which flow upon the earth, for some short distance at least, before they are absorbed beneath its surface.

But on this point we are not left to conjectures. We have direct evidence to prove that the sun exercises an electrical as well as a chemical influence upon the earth. Mrs. Somerville found that a sewing needle having one end exposed to the influence of the violet rays of the spectrum became magnetic in about two hours. The end thus exposed to the sun's action exhibited north polarity.* Similarly it has been shown by Mr. Christie that when a magnetised needle is made to vibrate in the light of the sun, the arc of vibration is more rapidly diminished in the sun's light than in the shade. Hence he concludes that the solar rays possess a sensible magnetic influence.†

We have, however, examples upon a very much larger scale of the influence of the sun in producing magnetic effects. I have already directed your attention to the currents of electricity which circulate upon the earth. Colonel Sabine, the highest authority in relation to magnetic phenomena, has furnished full evidence, from the exact coincidence in time of magnetic disturbances in remote parts of the globe, that these disturbances are irrespective of any local condition of the earth or of the atmosphere, that they are due to causes that are without; and, pointing out the correspondence of such periodical variations with the several conditions of the sun, he shows a relation between them which we can no longer refuse to admit. He shows that the maxima and minima magnetic variations are connected with the greater or smaller number of the dark spots present on the sun's disk. These dark spots, which have the appearance of being huge rents in the solar envelope, and which are thought to be indicative of violent whirlwinds sweeping over the face of the sun, or else of volcanic eruptions bursting through its outward shell, are productive of magnetic storms on the earth. Nay, there is, as Balfour Stewart observes, reason to believe that our luminary was on one occasion caught in the very act of disturbance. On September 1st, 1859, two astronomers, Messrs. Carrington and Hodgson, were, independently of one another, observing the sun's disk, which exhibited at that time a very bright spot, when about a quarter past eleven they noticed a bright star of light suddenly break out over the spot, and move with great velocity across the sun's surface. On referring afterwards to the Kew Observatory, at which place the position of the magnet is recorded continuously by photography, it was found that a magnetic storm had broken out at the very moment when this singular appearance had been observed.

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* The fact stated above I find is not admitted as altogether certain, as appears from the following quotation: "Dr. Morichini first called attention to an experiment in which a steel needle became magnetised by exposure to the violet rays of the sun. This experiment was repeated by many eminent persons, sometimes successfully, at other times not. Amongst others, Mrs. Somerville subjected a sewing needle to the influence of several rays of the spectrum, and found that the needle had become magnetic. Faraday, however, when at Rome in 1814, failed, under Morichini's own direction and working with Morichini's own apparatus, to magnetise a steel needle in the way described" (Harris's "Rudimentary Magnetism," second edition, p. 76).

This experiment evidently requires very careful manipulation. It is necessary that the influence of the earth's magnetism be neutralised. The violet rays of the sun, whilst they fall upon the needle and, unless in passing through the prism they are diverted from their course, traverse the upper surface of the needle from east to west, will at the same time fall on the ground, or whatever substance is immediately below the needle, and, supposing that substance to be conducting, produce to some extent a counteracting influence on the lower surface of the needle. But, over and above this, it is manifest that a common sewing needle presents too narrow a surface for the sun's rays to act upon. To allow the experiment to be fairly tried, the needle must be made wider in the centre, without being made any heavier. It is almost needless to observe that a needle magnetised in this way would differ from the ordinary magnet, and would correspond to the earth in having the positive current flowing upon its upper surface from east to west instead of from west to east. As, apparently, the experiment has been performed sometimes successfully, we may hope that the cause of its failure at other times may be brought to light and be satisfactorily explained.

† Webster's "Elements of Physics," first edition, p. 337.

I trust that I shall be able to give proof to satisfy you that the sun is the cause not only of those magnetic disturbances which from time to time sweep over the face of the globe, but also of those magnetic currents which at all times circulate upon the earth. I have already brought forward what appears to me convincing proofs that the sun exercises both a chemical and an electrical influence upon the earth; but, as it is of great importance that all doubt concerning this point should be removed before I consider the consequences that follow from it, I will endeavour to reach the same conclusion by a different line of argument, which, whilst it serves to throw light upon the question we are discussing, will at the same time introduce to our notice one of the most striking and beautiful discoveries of modern science.

LECTURE VIII.

THE COMPOSITION OF THE SUN AND OF THE EARTH HOMOGENEOUS.*

The elementary substances which enter into the composition of the sun and of the earth for the most part, if not wholly, the same—The inference to be drawn therefrom.

IT had long been surmised and suspected that the sun, as well as the other planets, was formed of the same material elements as our earth. The aerolites which from time to time have been cast upon the earth were found to be composed of the same materials with which we are familiar; and the opinion more generally received at the present day concerning the origin of these bodies is that they are planetary, revolving round the sun, and drawn out of their course by the influence of the attraction of a larger body across whose path their orbit lay. Now, however, we are furnished with proof of an unexpected kind that the substance of the sun and of the earth is identical, or at all events that a great many elementary substances are common to both; whilst it remains to be seen whether there are any appertaining to one which do not appertain to the other.

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* See Tyndall's "Heat a Mode of Motion;" Balfour Stewart's "Treatise on Heat," chap. 4.

And how has this discovery been made? By the analysis of the solar spectrum. Wollaston had observed a number of dark lines in the spectrum of the sun's light, and Fraunhofer had accurately studied and mapped out these lines, which were named from him Fraunhofer's lines. For a long time the origin of these dark lines remained a mystery, nor was this mystery diminished when it was found by Fraunhofer that a bright band, corresponding to the double dark band named D of the solar spectrum, was produced by the light of a flame containing sodium. Sir David Brewster prepared the way for the solution of the problem by showing that analogous—not identical—lines might be artificially produced by interposing a jar of nitrous-acid gas in the path of a beam of light. The inference naturally drawn from this fact was that the dark lines of the solar spectrum did not denote the absence of continuous light proceeding from the sun, but were due to the absorption of certain rays by some substance interposed between the sun and the earth. It remained, however, a doubt whether the stoppage of light occurred in the atmosphere of the sun, or in that of our planet, until the matter was finally settled by Kirchoff. He found that a sodium flame—or, in other words, sodium in a vapourised incandescent state—gives out the double line D; but that when it is not in an incandescent state it transmits other rays falling upon it, but stops this particular ray, and casts upon the spectrum a dark line D instead of a bright one. This is in accordance with the general law that bodies when cold absorb the same rays which they give out when hot. Thus sodium, which when cold is silver white, emits a deep yellow ray when in an incandescent state. And zinc, which when cold is a bluish white, emits when incandescent a deep purple ray. Hence he conjectured that the dark line D in the solar spectrum might be occasioned by the presence of the vapour of sodium in the solar atmosphere absorbing the ray of yellow emitted by the sun itself, the temperature of which would be higher than that of its atmosphere. This conjecture was strengthened by his finding that other dark solar lines corresponded exactly with the bright lines given out by different metallic vapours. It ripened into certainty when, the spectrum of solar light and the spectrum produced by iron volatilised in the electric flame being placed side by side, it was seen that for every bright line in the one—more than sixty in number—there was a dark line in the other. Professor Tyndall assures us that the chances are, mathematically considered, many millions to one in favour of the conclusion that iron exists, and that in great abundance, in the sun as well as on the earth. By means of the analysis of the solar spectrum, Kirchoff has detected in the atmosphere of the sun the presence, not only of sodium, whose conspicuous lines had in the first instance attracted notice, but also of iron, nickel, calcium, magnesium, barium, copper, zinc. As yet the presence has not been discovered in the sun of gold, silver, mercury, aluminum, tin, lead, arsenic, antimony, bismuth. I may mention, parenthetically, that the spectrum of the light of different stars has been subjected to the same kind of analysis, and that in Aldebaran and Alpha the presence has been detected of sodium, magnesium, hydrogen, calcium, iron, bismuth, tellurium, antimony, and mercury, and the presence of other elements in other stars ; so that, to speak generally, we may look upon all the planets and heavenly bodies as made of the same substance as our earth. I would not, however, have you infer that, because certain elements, such as gold and silver, have not yet been discovered in the sun, there is sufficient reason for us to believe that they do not exist there. All that we know is that, whatever the cause of it may be, whether, for instance, there is as great a scarcity of these precious metals in the sun as on the earth, their presence has not been detected in the sun's photosphere by means of the solar spectrum analysis, which brings to light the existence of the more common metals found on the earth.

It appears then that there is a considerable number of substances which are common both to the sun and the earth, if indeed it should not eventually be found that all the substances which belong to the one belong also to the other. It is known also that those substances which constitute the photosphere of the sun are present there in an active volatilised state. I have likewise put before you sufficient ground for believing that there is an interplanetary medium between the sun and the earth capable of transmitting any electrical influence which substances existing in a nascent state in the former would be calculated to produce in corresponding substances existing upon the surface of the latter. When, then, looking into the actual state of the earth, we find it to be in an electric or magnetic condition, we are surely justified in inferring, so long as no other evidence is brought forward to account for the fact, that the earth owes its magnetic condition to the action of the excited elements in the sun's photosphere. The ground which we have for holding this conclusion will appear stronger still when it comes to be seen that, just as those elements of the induced cylinder which are heterogeneous to the electrified elements of the charged ball exhibit negative electricity at the end of the cylinder nearest the ball, whilst those elements of the cylinder which are homogeneous to the excited elements of the ball transmit to the other end the positive electricity which is communicated to them; so in like manner the elements on the surface of the earth which are heterogeneous to the substances present in the sun's photosphere are electrified negatively, whilst the elements on the surface of the earth which are homogeneous to the substances in the solar photosphere are electrified positively, the positive and negative currents flowing in different directions one from the other.

LECTURE IX.

THE EFFECTS PRODUCED ON THE EARTH BY THE ELECTRIC ACTION OF THE SUN.

The principal effects are a terrestrial magnetic current and the rotation of the earth—A general statement in regard to these two facts, as also in regard to the electricity of the sun and the conductivity of the earth.

I AM coming now to the principal effects produced by the sun's electrical action upon the earth, viz. the generation of a magnetic current flowing from east to west upon the surface of the earth, and the rotation of the earth itself upon its axis from west to east. Let me begin with a general statement and elucidation of facts before I bring forward arguments in detail.

The sun revolves upon its axis from west to east in about twenty-five days. We learn this fact from the spots which are seen to traverse its disk from east to west on the side which is turned to us. The earth and the other planets of the solar system revolve in their orbits in the same direction as the sun, and move with a velocity which corresponds with their respective distances from it; as though they had been successively thrown off from it whilst rapidly revolving in a liquid state. The rotation of the earth upon its axis is likewise from west to east. The consequence of this is that the sun appears to go round the earth from east to west. The magnetic current which circulates upon the earth flows from east to west. Upon what ground or what authority do I make this statement? The theory of Ampère—to which I have referred as accounting satisfactorily for the complex action of one magnet upon another, and of a magnet upon a conducting wire, in whatever position in relation to one another they may be placed—supposes the current which flows round the magnet to go from east to west on its lower side, and from west to east on its upper side. And according to the same theory the magnetic current on the surface of the earth must flow in the same direction as the current on the under side of the magnet, *i.e.* from east to west. If this were not the case, we know from the ascertained electro-dynamic laws that the needle would be forced to assume a different position in order to put itself in accord with the earth's current.

But to understand how these effects, viz. the circulation of magnetic currents upon the earth, and the rotation of the earth upon its axis, may be produced by the electric action of the sun it is necessary you should call to mind how a body in a highly electric condition acts upon the different elements of a body which is brought under its influence. The positively charged ball acting upon the heterogeneous copper element of the brass cylinder causes negative electricity to converge from the farthest end of the cylinder to that nearest to the ball; acting upon the homogeneous zinc element of the cylinder it causes positive electricity to converge from the end of the cylinder nearest the charged ball to the end which is farthest from it and which is nearest to those adjacent bodies which contain elements for which it has an affinity. Now the sun, which is an immense globe in a permanently electric state, may be likened to the charged ball, and the earth, which is insulated and within the range of the electric influence of the sun, may be compared to the induced cylinder.

It may, however, be necessary that I should show more clearly than I have done that the sun is in relation to the earth in an electro-positive state. What we learn from the analysis of the solar spectrum is that different metallic substances are present as well on the surface of the body of the sun as in its vaporous photosphere, in the one case in an incandescent, in the other in a volatilised state. These metallic substances, as you know, are electro-positive. Recent investigations into the nature of those red prominences which become visible in eclipses have established the further fact that the photosphere of the sun is enveloped by a sea of ignited hydrogen. This element, viz. hydrogen, if not metallic, possesses at all events most of the properties of a metal, and—which bears upon the point under consideration—is in relation to non-metallic substances electro-positive.

If then the sun be a positively charged ball, in what way will it act upon the earth? Were the sun fixed and stationary it would act on the earth in the same manner as the charged ball acts upon the insulated cylinder. It would cause negative electricity to flow from every part of the earth's surface to that side which was turned towards the sun, and positive electricity to accumulate upon the opposite side, the earth itself being drawn towards the sun by the force of the negative electricity generated upon its surface, and being propelled from the sun by the force of the positive electricity exerted in the opposite direction. But, inasmuch as the sun is not stationary, but moves from east to west on the side facing the earth, it will, so far as the earth is a conductor, cause a negative current to flow on the earth's surface in the direction towards itself, *i.e.* from west to east, and a positive current to flow in the direction away from itself, *i.e.* from east to west. And, in so far as the earth's surface is non-conducting, the negative electricity generated upon it will expend its force upon the air, throwing it by induction into a positive electric state; and the positive electricity, which is transmitted by the sun, will, so far as it finds no pathway upon the earth, and is not taken up by the air, be absorbed beneath the earth's surface. These different electric forces acting simultaneously upon the earth in a horizontal and perpendicular direction cause it to rotate upon its axis (Fig. 22).

This is my statement of the facts of the case, the correctness of which I hope to establish in my subsequent lectures.

You may perhaps demur to any comparison being instituted between the action of the sun upon the earth and that of the charged ball upon the cylinder. You may say that, admitting the substances of which the sun and the earth are formed and those of which the ball and the cylinder are composed to be in both cases alike, yet, in regard to their electric character as well as their conducting power, there is no analogy between the one and the other. It must be understood, however, I do not adduce the example of the ball and the cylinder as an exact parallel case to that of the sun and the earth, but as one which serves to illustrate clearly the principle of inductive action and the mode in which it operates. Were we to substitute in place of the brass cylinder a pith ball, we should still have the same effects produced, although not in the same degree. Now granting that the earth possesses less electric energy and conducting power than the brass cylinder, undoubtedly it possesses more than the pith ball.

I may here observe it is usually maintained that the negative and positive electricity induced upon the insulated cylinder are equal, because when the charged ball is withdrawn the two appear to neutralise one another. But if we admit that both owe their origin to the presence of the charged ball, we should naturally expect that they would both disappear when the ball is taken away, whether they were equal or not. I might allude to the pith ball being drawn by the force of attraction to the charged brass ball. This fact seems to prove that, in this particular instance at least, the negative electricity excited on the pith ball is in greater force than the positive. But it is no part of my argument to determine whether the two currents flowing upon the earth are equal in power one to the other. Whether this be so or not must, I think, in great measure depend upon the proportion which exists between the positive and negative elements upon the surface of the earth, and upon the conducting power which belongs to them.*

Let me remind you in the next place that what I am called upon to prove is not that there is an electric current flowing upon the surface of the earth; the observations of Sabine and others have indubitably established the fact of the existence of this current in every part of the earth, and of the gradual increase of its intensity as we pass from the equator to the poles. The twofold nature of this current is also clearly demonstrated by the opposite manner in which the needle acts at the north and south poles. Neither am I required to prove that the earth is a conductor. The fact of this magnetic current traversing its surface in every part is itself a sufficient proof that the earth is, I do not say a good conductor, but still a conductor of some sort, however imperfect a one it may be, not to speak of the almost unlimited capacity which the earth has of absorbing electricity. I may be permitted to call your attention to the fact that at least three out of the four parts of the earth's surface are covered with water; and water, you are aware, shows itself in the galvanic trough to be conducting. It is also well known that in order that the electric machine may be made to work efficiently it is necessary to be kept perfectly dry, because even the moisture deposited upon it in a damp atmosphere is sufficient to carry off the greater part of the electric fluid which is generated. Again, of the different elements which enter into the composition of the dry land, some—*e.g.* calcium, carbon, silicon—are not in themselves bad conductors. It being admitted then that the earth is a conductor of electricity, and that it has, as a matter of fact, a magnetic current circulating upon it, all that is, strictly speaking, necessary to be done is to show, first, the connection between the sun's electric action and the existence of the magnetic currents of the earth; and, in the next place, the connection between the existence of these magnetic currents upon the earth and the rotation of the earth upon its axis. I proceed then first to the proof that the circulation of the magnetic current upon the earth from east to west is due to the sun's electric action. Bear in mind, however, what I have said before, that when I speak of a magnetic current traversing the earth you must not understand me to mean the actual movement of a material fluid along its surface, but simply the constant and uninterrupted transmission of a very subtile and active force.

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* As a general rule it would seem that the positive is more powerful than the negative current in a primary circuit, and that the negative is more powerful than the positive current in a secondary circuit. The spark which proceeds from the rubber, or negative conductor, of the electric machine is shorter and less brilliant than that which proceeds from the positive (Noad's "Electricity," p. 32). In the production of the electric light the quantity of matter transferred from the negative to the positive terminal is much less than that which is carried from the positive to the negative. We are told also (ibid. p. 245) that, when the arc discharge takes place between two wires attached to the terminal plates of an extended series of the voltaic battery, the positive electrode becomes red-hot, and ultimately fuses, whilst the negative electrode remains comparatively cool, whereas when the discharge from an induction coil is taken in air or in vacuo it is the negative terminal which is most heated. I do not put forward these facts as in any way decisive on the point. The character of the medium, according as it has a greater affinity to the positive or the negative current, will act differently upon the one electrode and the other, and the greater or less resistance which the currents meet with will augment or diminish the amount of heat which is evolved.

LECTURE X.

THE MAGNETIC CURRENT.

Why the magnetic current flows upon the earth from east to west —What becomes of that portion of it which is stopped in its course.

THE sun may be taken to be a charged ball having metallic elements in a highly electric state diffused over its superficies, and volatilised in its atmosphere. Outside of its atmosphere is a vast sea of ignited hydrogen. Has the earth on its surface substances which have a chemical relation to the electro-positive elements above mentioned? Because, if there be any substances which have an affinity to these elements, they must become to some extent negatively electrified; and if there be others which are in their nature homogeneous to them, they will become electrified positively. Oxygen is a substance which has a strong affinity to the different metals as well as to hydrogen. And in combination with other elements it constitutes at least three-fourths of the terraqueous globe. Water, which covers nearly three-fourths of the surface of the earth, contains as much as eight-ninths of its weight in oxygen. The solid crust of the earth consists, probably, to the extent of a third part of its weight of the same principle. Silica, carbonate of lime, and alumina, the three most abundant ingredients of the earth's strata, are to the extent of nearly half their weight composed of oxygen. It may be objected to me that it is only in the form of combination with other substances that oxygen is met with upon the surface of the earth. It is true of course that elements in their simple state are much more liable to be acted upon either chemically or electrically, but it would be altogether a mistake to suppose that elements in a state of chemical combination are insensible to electrical influences. Oxygen exists in a state of chemical combination with hydrogen in water; but if the electric spark be made to pass through water it will be decomposed into its constituent elements. Again, oxygen exists combined with other substances in the pith ball; but the pith ball is drawn into contact with a charged ball which is brought near to it, being attracted through its electro-negative elements if the ball be electrified positively, through its electro-positive elements if the ball be electrified negatively. There can be no doubt then that negative electricity will be developed on the surface of the earth, from the fact of oxygen, not to speak of other elements of a similar character, being largely present there.

In like manner, it may be shown that the earth contains many substances upon its surface of an electro-positive character. Hydrogen is one of those substances. It is homogeneous in its nature to the metallic and other elements of which I have spoken as existing in a nascent state upon the superficies of the sun, and in combination with other substances is present over a large portion of the surface of the earth. I have said nearly three-fourths of the globe is covered with water. We know, from the decomposition of water, that, of the two elements of which it is formed, hydrogen is very much lighter than oxygen, is twice as expansive, and is presumably therefore uppermost on the surface. On the land there are not a few substances into which hydrogen enters as an essential ingredient. Of all plants and herbage, and generally of all combustible and organic matter, it is a constituent. The principal substances of which the solid crust of the earth is formed are, as has already been stated, silica, carbonate of lime, and alumina, and the components of these substances are oxygen and certain metallic and mineral bases: the first-named of these is electro-negative, the latter are electro-positive. Enough, I think, has been said to show that the earth contains elements some of them similar to, and others the counterpart of, those elements which are present in an electric state upon the superficies of the sun, and that we have here sufficient cause to account for the development of that electricity, both positive and negative, which we meet with upon the surface of the earth.

This electricity thus generated upon the earth flows from east to west. How is this fact to be explained? I have said, if the sun were stationary, the negative electricity excited upon the earth would be collected upon that side of it which was turned towards the sun, and the positive electricity would be collected on the opposite side; but as the sun is not stationary, but moves on the side facing the earth in the direction from east to west, it will cause the negative electricity which is developed upon the earth to flow in the direction towards itself, *i.e.* from west to east, and the positive electricity which it communicates to the earth to flow in the direction away from itself, *i.e.* from east to west, in so far as the surface of the earth is a conductor. I will quote the law which applies to cases of this kind, which is expressed by Lenz in the following words: "When a current is induced in a conductor by the motion of a magnet or current, or of the conductor, the current induced flows in such a direction that its action opposes the motion producing it."* I am not called upon to prove this law, the truth of which is admitted, and has been arrived at by the logic of facts, but I may direct your attention to what is called the magnetism of rotation, as furnishing an illustration of it. If a magnet be made to rotate immediately above a copper plate, it will cause electric currents to be developed on the surface of the plate. Or if the conducting plate be made to revolve immediately above or below the magnet, electric currents will be generated upon the surface of the plate. This is not indeed the only effect produced. Not only are currents set in motion, but, if the plate be made to revolve with sufficient rapidity, these currents will draw the magnet after them in their revolution. This last-mentioned fact I will leave, however, for future consideration; at present I wish only to direct your attention to the proof which we here have of the generation of a current whenever a magnet revolves above a conductor, or whenever a conductor revolves below a magnet. Now, the sun is a magnet, or, more properly, a body in a highly electrified state; and the earth is an insulated conductor, containing upon its surface elements both electro-positive and electro-negative, and capable therefore of being electrified by induction. What effect, then, will follow from the revolution of the sun upon its axis? Electric currents will be set in motion upon the surface of the earth. And in what direction will they flow? An induced current flows in the contrary direction to that of the current which induces it, and tends to arrest the motion of the body which causes the induced current. The sun therefore, which is a positively electrified body moving from east to west on the side turned towards the earth, will give rise to an inverse current flowing upon the earth from west to east. For an inverse current, we are told,* the term *negative*, and for a direct current the term *positive* current may be employed in reference to induced currents. Therefore the inverse current which is induced upon the surface of the earth by the rotation of the sun is a negative current, which so far as the conducting power of the earth permits will flow from west to east. Where there is a negative current there will likewise be a positive one, and this positive current, which will be a direct one, will flow in a direction corresponding to the motion of the sun, *i.e.* from east to west. We have, then, a negative current flowing from west to east, and a positive current flowing from east to west. It is usual to call the direction in which the positive electricity flows, the direction of the current; and therefore, speaking of the double magnetic current upon the earth, we say that it flows from east to west.*

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* Ferguson's "Manual of Electricity," p. 202.

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* Ibid. p. 184.

It would not be right for me to pass on without taking notice of a phenomenon which is very commonly referred to as throwing important light upon the nature of the law of current induction, and which may seem to be opposed to the conclusion which I have drawn, because it establishes the fact that a current of electricity which continues to flow along a conductor does not induce in a neighbouring conductor a continuous but only a momentary current. Let two copper wires be carried for a certain distance parallel and near to each other, the ends of the one wire being connected with a galvanic battery, the ends of the other being connected with the binding screws of a galvanometer (Fig. 21). If a positive electric current be sent along the primary wire, a negative current flowing in the opposite direction will be set in motion on the secondary wire, as shown by the deflection of the needle. But this induced current is only momentary. Although the electric current on the primary wire continues to flow, the current induced on the secondary wire ceases, and the needle falls back to its former position of rest. If, however, the battery circuit be broken, and the primary current be stopped, a fresh current of momentary duration is shown by the needle to pass along the secondary wire. The direction of the current this time is the reverse of that which took place before. But if, whilst the battery current continues to flow steadily along the primary wire, the secondary wire be made at one time to approach nearer to, and at another time to recede farther from, the primary wire, momentary currents will be induced in the secondary wire, viz. an inverse current in the former case, a direct one in the latter. But as long as the two wires continue relatively to each other in the same position, the needle, which is not moved from its place of rest except by an electric current, gives no indication as to the state in which the secondary wire permanently remains. Again, if whilst the two wires continue relatively to each other in the same position the strength of the primary current be at one time increased, at another time diminished, momentary currents in the secondary wire will mark the changes in the primary, an increase causing an inverse, a decrease a direct current. We see, then, that a continuous flow of a current upon a primary conductor does not give rise to a continuous flow of a current upon a secondary conductor. It is only when an electric change, either absolute or relative, takes place in the one, that a corresponding change manifests itself in the other. Upon this understood principle electro-magnetic machines are constructed in which by the continual making and breaking of the circuit a constant electric action is maintained.

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* It is not meant that either the positive or negative current of which the magnetism of the earth is made up is in reality a single current flowing to the north or south pole. Each of these currents is itself made up of an infinite number of smaller currents generated upon every part of the earth. A certain number of these reach the positive or negative pole; the far greater part of them, however, after proceeding a longer or shorter distance, are arrested in their passage along the surface of the earth for want of a conducting channel, and spend their force upon the air above in the case of negative, upon the earth beneath in the case of positive electricity.

I will briefly show that there is nothing here which prevents us from holding that the electric action of the sun is the source of the magnetic current which flows continuously upon the earth. First, however, let me observe that it would be a mistake to suppose that, because, for reasons which I will explain, the current induced on the secondary wire is but momentary, all action of the primary upon the secondary wire ceases at the same time. The action of the primary lasts as long as it remains in an electric state, and it remains in an electric state as long as the current continues to flow over it. To show that the secondary wire is affected, not merely momentarily but continuously, by the action of the primary, let me refer you to an instance which has already been given of the continued inductive effect which a primary is capable of producing. If an iron bar be inserted in a coil through which a current of electricity is made to pass, an electric throb takes place and a click is heard. The bar, round which a momentary current passes, is suddenly lengthened, and continues thus stretched as long as the current flows through the coil. When the current is stopped another throb marks the sudden shortening of the bar to its original length. The explanation of this phenomenon has already been given. Now there can be no doubt that in a proportionate degree the same thing must happen in relation to the secondary wire when brought under the influence of a primary parallel wire along which a current flows. The secondary will be held in a state of electric tension, even though it has no continuous current flowing over it. The condition therefore of a secondary conductor of a closed circuit, under the influence of a primary conductor, will be precisely the same as that of an insulated brass cylinder under the influence of a charged ball, and we should consequently expect the same effects to follow in the one case as in the other. And in reality we do find that the effects which take place in the secondary conductor under the influence of its primary which have been stated above correspond to those which take place in the insulated cylinder under the influence of the charged ball. When the cylinder is brought within the range of the influence of the positively excited ball, a momentary reverse or negative current is set in motion on the cylinder in the direction of the ball; a direct or positive current flows the other way. The current is but momentary, but the concentration of negative and positive electricity at the two ends of the cylinder continues as long as the charged ball remains present. When the ball and the cylinder are brought still nearer together, a fresh current of similar character is set in motion on the cylinder; when they are removed farther apart, the current on the cylinder recedes in the same proportion. When the charged ball is taken away, the current upon the cylinder flows back altogether. The similarity of action between the primary and secondary wire, and between the charged ball and the cylinder, is, you see, perfect. But, you may ask, why is it that the current induced upon the secondary wire does not continue to flow as long as that upon the primary continues to do so, whereas the earth, which has a current always passing over it, is able to magnetise an iron rod which is suspended in the line of the inclination and declination of the needle, or, in other words, to cause a continuous current to flow upon its surface? My answer is that the action of the primary conductor upon the secondary wire of a closed circuit is, as I have said, similar to that of the charged ball upon the insulated cylinder, but not similar to that of the earth upon the magnetic rod or needle. In what do they differ from one another? The poles of the magnetic needle may be likened to two electrodes, and the intervening air to the liquid in the decomposing cell. A certain portion of the magnetic current passes in this way from one pole to the other, whilst another portion is dissipated and lost; so that the earth always finds in the magnet a capacity to receive a further electric supply, and out of its own inexhaustible store it furnishes whatever supply is needed. The secondary wire, on the other hand, like the insulated cylinder, has no outlet by which the electricity communicated to it can pass away; therefore it is only capable of receiving a fixed limited supply. No doubt some portion of the amount received is gradually dissipated into the air; but it escapes so insensibly that the small quantity which is added in its place does not give rise to a current sufficiently strong to affect the needle of the galvanometer.

But though a secondary conductor gives no perceptible sign of a current passing over it so long as that current has no outlet afforded to it, yet, if either the primary or the secondary be made to revolve, a current will immediately be set in motion on the secondary as well as on the primary. Thus a copper plate suspended over a magnet will give no visible sign of a current circulating upon it, but let either the magnet or the plate be made to revolve, and the presence of a current upon the surface of the plate will at once be made manifest. It may be, perhaps, that a current is first generated in the surrounding air by reason of the attraction which exists between its oxygen element and the excited surfaces of the primary and secondary; and that, in consequence of the greater facility thereby afforded for the discharge into the air of the electricity accumulated upon the plate, a current is developed upon its surface. But let the explanation of it be what it may, the fact is undeniable that when a magnet or an electrified body is set in motion it gives rise to currents in a neighbouring conductor.

It would be, I consider, more correct to compare the electric action of the sun upon the earth with the electric action exerted by the earth on the magnet, than to compare it with the electric action exerted by a primary upon a secondary conductor, inasmuch as the electricity communicated by the sun to the earth is to a great extent absorbed beneath the earth's surface or dissipated into the air, so that an opportunity is given for the free development of a current upon its surface. If, however, the electric action of the sun upon the earth should be compared to that of a primary upon a secondary conductor, it must be compared to that of a primary body which is in motion, in which case, as you are aware, a current is always generated. Let us briefly look at the facts before us in this light.

The sun is a powerfully electrified body revolving upon its axis. The earth is an insulated conductor brought within the range of the sun's influence, and having upon its surface both elements which are homogeneous and elements which are heterogeneous to the substances which are in an active state upon the superficies of the sun; and flowing round the earth there are currents such as our knowledge of the above-mentioned facts would have led us by anticipation to expect as the result of the inducing action of the sun exerted upon the earth. I might say the necessary result of the electric action of the sun upon the earth, for, in the first place, it cannot be doubted that the constituents of which the earth is formed are of a nature to be affected by the electric influence of the sun. The constituents of the earth and the constituents of the sun are, as a matter of fact, the same, and if those of the latter are in reality raised to a highly electrified state, those of the former must be capable of being raised to a similar state. In the second place, it cannot be denied that the earth lies within the range of the sun's electrical influence. The solar rays, as I have stated already, are found, when analysed, to be composed of rays of heat, rays of light, and rays of chemical or electrical power. And the rays of the sun are unceasingly falling over considerably more than one-half of the globe. Being refracted upon their entrance into the denser medium of the atmosphere, they reach the earth both before the sun has risen upon it, and after it has sunk beneath the horizon. The twilight which is the consequence adds considerably to the length of the days in those parts which are distant from the equator. But the chemical rays of the sun are even more refrangible than those of light, and descend upon the earth a longer time out of the twenty-four hours.* Hence it is that electricity begins to exert its energies upon the earth before the sun has risen, and continues to exert its power for some time after it has gone down. It is to be observed also that when the heavens are overcast with clouds, or the earth is shrouded in mists, the continuity of the interplanetary medium between the sun and the earth remains unbroken. The rays of the sun are only partially intercepted, and we have reason to think the rays of chemical power in a less degree than those of light. Now if it be granted that the solar ray possesses in it electric force, however small it may be, it must of necessity be admitted that the countless myriads of rays poured down every moment upon more than an entire hemisphere must generate a power which is immensely great.

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* As the redness of the morning and evening sky is due to the refraction and reflection of the red beams of the solar light passing through the vapours of the atmosphere, so the blueness of the sky outside the circle of the more direct light of the sun seems due to the fact that the rays of light producing this colour are alone refrangible in the attenuated air of the highest regions above the earth.

The capacity of the earth as a conductor of electricity is, it may be said, extremely low. Undoubtedly it is. Were it not so, the current of electricity set in motion upon its surface, gathering strength as it passed along, would give rise to phenomena much more remarkable than those which we at present witness. Instead of auroras lighted up in the polar regions and thunder-storms produced in other parts of the earth, together with the ozonising of the oxygen in the air, we should have our earth lit up, like Venus, with a fluorescent light, or surrounded, as appears to be the case with the planets Saturn and Jupiter, by luminous zones or coloured belts formed by the confluence in the air of currents of positive and negative electricity.

But what then becomes of the amount, unquestionably very great, of electricity which is generated upon the earth, and which not finding a pathway upon its surface either does not flow at all, or after it has begun to do so is sooner or later arrested in its passage? I have said, in so far as the earth is a conductor, the negative electricity generated upon it will flow in the direction towards the sun, from west to east, and the positive electricity communicated to it will flow in the direction from the sun, from east to west; and in so far as the earth is non-conducting the positive-electric current will be absorbed into the earth; the negative electricity accumulated upon its surface will discharge itself into the air, acting as it does when accumulated upon the surface of the insulated cylinder or pith ball.

The sun is a positively electrified body, and the positive electricity of which we are here speaking is that which is communicated to the earth by the action of the sun's rays. On the other hand, the negative electricity to which we are referring is that which is developed on the earth itself through the affinity which its negative elements have to the positive elements of the sun. Now there can be no question but that the positive electricity from without will, if it does not meet with a conducting substance upon the surface of the earth, be absorbed beneath its surface. When any positive electricity is conveyed from the electric machine or from the galvanic trough to the earth, if it does not fall upon a substance which conducts it along the ground, it is immediately absorbed beneath the surface. The same thing then will happen here. You may say that any negative electricity which passes from the electric machine or the galvanic trough will, just like the positive electricity, be immediately absorbed. And so I freely admit any negative electricity which comes from the sun will be in like manner absorbed by the earth. But the sun being not negatively but positively electrified, the negative electricity which comes from it will be comparatively small in quantity, and we may omit to take any account of it. What, however, will become of the negative electricity which is developed upon the earth's surface, and which for want of a conducting channel cannot flow upon it? Its action, I have said, will be similar to that of the negative electricity accumulated upon the end of the cylinder or upon the side of the pith ball next to the charged brass ball. Now this negative electricity which converges upon the nearest end of the cylinder, or side of the pith ball, is not absorbed into the cylinder or into the pith ball, but in the first place it stimulates the particles upon their surface into action; in the next place it charges the air which intervenes between these particles and the inducing body; and, lastly, it attracts the inducing and the induced bodies towards one another. In the case of the electric light, however powerful the current of electricity may be, it cannot draw the two terminals nearer together, but it causes particles to fly off from the positive to the negative terminal, and also, though in a less degree, from the negative to the positive terminal. It has further been demonstrated by spectrum analysis that whenever a spark passes between two bodies particles are carried off in an incandescent state from one body to the other. We are led to infer therefore that, when the negative electricity developed by the sun's influence upon the earth cannot find a pathway upon its surface to its own pole—it is probable that the two poles are connected together through the medium of the highest regions of the air—it will exert its power upon the air above. We find accordingly that the upper atmospheric strata of the earth are positively electrified, and that as a rule they remain in that state until some time after the sun has gone below the horizon.

When, however, the negative electricity accumulated by the action of the sun upon the earth's surface has had sufficient time to disperse itself, the tension of positive electricity in the upper regions of the air falls enormously.

Besides the charging of the atmosphere and the clouds floating therein with electricity, other effects also will follow. There is reason to believe that, the affinities between the excited negative elements on the surface of the earth and the excited positive elements on the superficies of the sun being stimulated into action, the earth will be attracted electrically towards the sun, in the same way as the pith ball is attracted electrically towards the brass ball of the electric machine. It is true that the pith ball and the charged brass ball are connected through the medium of the air, whereas it is plain our atmosphere does not connect the sun with the earth. But if the rays of the sun's light and of the sun's positive electricity can travel from the sun to the earth, there is no doubt that the rays of the earth's reflected light and of its negative electricity can, by the same medium, travel back from the earth to the sun. It may be urged that no luminous electric discharge can pass through a perfect vacuum; and by a perfect vacuum we mean a space which is void, not of that ethereal medium which pervades all parts of the universe, but of those gaseous elements of which the air is composed. It does not, however, follow that because an electric current cannot produce luminous effects where no gaseous elements are to be found, an electric current cannot pass where these elements are not present. We are told that a vacuum tube in a state to show stratified discharges is so good a conductor that sparks from the outer terminal of the induction coil will pass to one of its wires—the other being attached to the inner terminal—one inch in length through the air.* If now two such tubes be attached, one to the inner, the other to the outer terminal of the coil, and the circuit be completed with a third vacuum tube similar to the other two, the stratifications in all three will be clear and distinct, as if the circuit had been completed by a single tube; but if the circuit be completed by a third tube which, instead of being like the other two, is a perfect vacuum tube, the discharge in the two former tubes will be reciprocating, whilst in the perfect vacuum tube no luminous appearance will be perceptible. From the description here given it seems impossible to doubt that the electric current really passes through the perfect vacuum tube from the one luminous tube to the other, although its passage is not rendered visible.

Again, we find that the magnetic current continues to flow alike from one pole of the horseshoe magnet to the other, whether a tube which has a luminous discharge passing along it, or one which we call a perfect vacuum tube, be interposed between them. Now in the first case it can hardly admit of doubt that the magnetic current passes through the tube, inasmuch as it deflects the stream of light from its course, and, when the force of the magnet is great, extinguishes it altogether. But if the magnetic current has power to pass through the non-conducting glass, there seems little reason to doubt its power to pass through the vacuum tube. We are, in fact, told that it is a peculiarity of magnetic influence, that it should be transmitted through all substances not magnetic with equal facility *—which is as much as to say that electricity of magnetism more readily lays hold of the ethereal medium as a conductor than other forms of electricity do. It is true that the magnetism of the earth is not the magnetism of the iron bar; but the planets around us are of the same substance as our earth, and we know that by means of the ethereal fluid intervening between us and them the light which is kindled in them and the influence which is generated upon them by electric action reach to us. Thus, as I have said already, a fluorescent light, which is considered, like the aurora borealis on the earth, to be of magnetic origin, is seen by us to shine over parts of the planet Venus which are screened from the rays of the sun. In like manner, by means of delicate instruments, it has been proved that the moon radiates upon the earth a small degree of heat, and exerts also a certain amount of electric force.

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* Noad's "Student's Textbook of Electricity," p. 337.

There cannot therefore be any real ground to doubt that by means of this ethereal fluid a reciprocal electric action is continually going on between the sun and the earth. I abstain from saying more upon this point, because, as it seems to me, abundantly sufficient evidence has already been furnished of an electric influence exerted by the sun upon the earth, and the only kind of reciprocal

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* Ferguson's "Electricity," p. 3.

action for which I am here contending is that electrical attraction which is never found to be absent whenever two bodies, one positively, the other negatively excited, come within the range of one another's influence. It still remains for me to show that the rotation of the earth upon its axis is a result brought about by the magnetic currents generated upon its surface. But before I enter upon this last part of my subject I wish to clear up certain intricacies in the movement of this current, the explanation of which I was obliged to defer to the present time. As far as I am aware, no theory has yet been put forward which can be looked upon as satisfactorily accounting for the normal direction and the periodic variations of the magnetic current. If the theory which I am advocating proves itself equal to the task, this assuredly ought to tell very greatly in its favour.

LECTURE XI.

THE NORMAL DIRECTION OF THE MAGNETIC CURRENT.

What is the normal direction of the earth's current?—By what local and other influences is it modified?

I RESERVED to this time the consideration of a certain number of points relating to terrestrial magnetism which I could not well attempt to explain before. What I have to say on this difficult subject I shall endeavour to compress in as few words as possible. The magnetic current flows upon the surface of the earth from east to west, as has already been said, and, being communicated to the needle, flows upon its lower side from end to end in the same direction, thereby causing the needle to point to the north and south poles of the earth. But when we come to examine into the matter more closely, we find that the needle hardly anywhere points due north and south, but, to speak in a general way, points over one half of the globe to the east and over the other half of the globe to the west of the north pole, as you will see by referring to the magnetic chart* drawn up with great care by Colonel

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* This chart, representing the lines of equal declination upon the earth, belongs to the epoch 1840. The course of the magnetic current has been traced upon it in agreement with those lines.

Sabine. What is the explanation of this fact? Let the path of the sun be traced out upon the earth, and it will be found to ascend on one side from the tropic of Capricorn to the tropic of Cancer, and to descend on the other side from the tropic of Cancer to that of Capricorn. The magnetic current flows everywhere round the earth in a line almost parallel to the sun's path, and the needle resting at right angles upon this line will point therefore to the east of the north pole where the line ascends from the tropic of Capricorn to that of Cancer, and to the west of the north pole where the line descends from the tropic of Cancer to that of Capricorn. In reality, as you are aware, the sun does not go higher at one time and lower at another as it moves forward in the plane of the ecliptic; but the inclination of the north pole of the earth is the cause why the plane of the ecliptic, cutting the equator in two different places, reaches on one side twenty-three and a half degrees above and on the other side twenty-three and a half degrees below it. As, however, the earth whilst performing its revolution round the sun preserves always the direction and obliquity of its poles unaltered, the magnetic current will flow always in the same direction.* The magnetic current will, however, not deviate so far from the line of the equator as the sun's path upon the earth does. The sun itself is not perpendicular to the plane of the ecliptic, but inclines to it in the same direction, though not in the same degree, as the earth. This inclination of the sun's axis, though it does not affect the line described by the sun's pathway upon the surface of the earth, because that line corresponds to the plane of the ecliptic, yet it does affect the direction in which the magnetic current flows upon the earth. The axis of the sun having an inclination of 7° 20′, and the axis of the earth an inclination of 23° 30′ in the same direction, the magnetic current which is generated and set in motion upon the earth by the rotation of the sun upon its axis will deviate from the line of the earth's equator, rising above it on one side and falling below it on the opposite side about 16° 10′, *i.e.* the difference between the degree of the inclination of the earth and that of the sun. As we shall see later, Duperrey arrived at very nearly the same conclusion as the result of his careful observations on the line of the magnetic equator.*

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* Strictly speaking, the deviation of the sun's path from the line of the equator agrees very nearly, but not absolutely with the deviation of the earth's poles from the perpendicular of the ecliptic. The sun does not act, in virtue of the law of gravitation upon the earth taken by itself, but upon the earth taken in conjunction with the moon. The plane of the ecliptic passes through their common centre of gravity, and, in consequence of the ever-changing position of the moon in relation to the earth, is at one time a liltle above and at

You may perhaps have some difficulty in understanding how it is that whilst the earth rotates upon its axis the magnetic current should always continue to flow upon its surface in the same direction. Suppose, for instance, the sun to be at the time of the autumnal equinox upon

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another time a little below the line which the sun would describe upon the earth if it had to do with it alone. We have here one of the many causes why the needle never remains for any length of time steadily in the same position.

* "Rudimentary Magnetism," p. 265.

the equator in the eastern hemisphere. The current generated there would ascend in an oblique direction towards the tropic of Cancer, and in like manner the current generated above the tropic of Cancer would flow obliquely towards the arctic circle. The earth turning upon its axis, the sun would of course go round the earth very nearly, though not exactly, upon the line of the equator,* and the current generated by it would everywhere, it may be thought, ascend from the equator to the tropic of Cancer, and in like manner from the tropic of Cancer towards the arctic circle. In that case the current would be everywhere in the northern hemisphere an ascending current, and the needle would therefore point at London, as it does at Calcutta, to the east of the north pole; whereas we know it points at London about twenty degrees to the west. It is necessary, however, you should bear in mind that the sun's path upon the earth is neither an ascending nor a descending line; it is, in itself, a straight line. If we say that it rises at one time and falls at another, the reason is because the sun in its annual circuit round the earth at one time approaches nearer to the north pole, and at another time recedes farther away from it; and the reason, again, of this, as has already been observed, is because the pole of the earth is not perpendicular to the plane of the ecliptic, but is inclined to it at an angle of sixty-six and a half degrees. The sun finds itself nearest to the north pole at the time when it overhangs the northern boundary of Hindostan. After touching that highest point, each circuit it makes round the earth carries it farther away from the north pole, until, when it overhangs the tropic of Capricorn, it has reached the greatest distance from it. Now the magnetic current, if we leave out of consideration the influence of secondary and exceptional causes, flows everywhere and always upon the earth's surface in a straight line parallel to the sun's path; but it is called an ascending current when it is approaching towards the north pole, and a descending current when it is receding from it. In the former case it causes the needle to point to the east of the pole, in the latter to the west. The British Isles being intermediate in position between the point where the current is nearest to the north pole and the point where it is farthest from it, the current there will be a descending current, and will cause the needle to point to the west of the north pole.

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* I have said the sun will go round the earth very nearly, but not exactly, upon the line of the equator, because at the end of three months the sun will be found to have risen gradually from the line of the equator to that of the tropic of Cancer.

You may, however, put this same objection in another form, and say the magnetic current flows over the surface of the earth in a direction parallel to the line of the ecliptic. If the axis upon which the earth rotates corresponded with the axis of the ecliptic, no change in the course of the magnetic current would take place. But this is not the case. The earth rotates upon an axis which is inclined to that of the ecliptic at an angle of twenty-three and a half degrees. Therefore whilst the earth performs its diurnal revolution, every place upon its surface will be carried round, not in a straight line corresponding to the ecliptic, or sun's path, but in a line which alternately rises and falls twenty-three and a half degrees in relation to it. This is true, but if you bear in mind what I have already said, viz. that the magnetic current which the sun generates upon the earth is a current which in reality flows everywhere in the same direction, and if you bear in mind also that the rotation of the earth does not change the relation in which any place stands to the north pole of the earth, you will at once see that the rotation of the earth will not produce any such change as at first sight it might be supposed it would produce upon the direction of the current and the declination of the needle. I do not mean to say that the rotation of the earth will produce no change whatever upon the magnetic current. It will produce effects which, though imperceptible in their diurnal amount, will, in the course of years, bring about great changes over the whole earth. Of these I shall have to speak when I come to the secular variations to which the needle is subject.

What I have here done is to set before you what may be called the primary or normal direction of the earth's current; and what I next proceed to do is to consider the disturbing effect which is produced by local influences as well as by others of a more general character.

To begin with local influences, they exist in some degree, there is reason to think, everywhere. They produce in many places results such as we could not have foreseen or have anticipated as at all likely to happen. As a rule we find the needle exhibits less irregularity in its movements out on the open sea. Nevertheless places are met with in sailing over the wide ocean where the needle by its disturbance indicates the presence beneath the waters of points of strong attraction. Sir J. Ross * speaks of passing over one of these extraordinary magnetic points, such as Sir E. Parry had observed in his second voyage to the arctic seas. In channels running between groups of islands, more particularly where, as in the Pacific Ocean, the islands are formed of coral limestone or of volcanic rock, the movement of the needle is very complicated. But it is principally upon the land or in connection with the land—*e.g.* on coasts—that local influences make themselves felt in a very marked manner. With reference to the island of St. Helena, Sir J. Ross tells us, "Here, as invariably on all volcanic islands, it was impossible to obtain correct measures of the magnetic elements by reason of the large amount of the disturbing influence of the rock itself. So powerful was it in this particular instance, that even at the distance at which our ships were anchored it produced such anomalies in the result of our observations for the deviation of the dip, and variation, and intensity, as to mask the ordinary effects of the ship's iron." † In Jamaica, where during the whole of the last century all surveys of property were conducted solely by the compass, it has happened, fortunately, no change of declination has taken place, although at a certain distance on every side around a very considerable variation has during the same period been going on. This anomaly, which manifests itself in the pointing of the needle in this and many other places, is attributed for the most part to the presence on the surface of the earth of ferruginous or such-like magnetic elements, or else to the existence undergound of volcanic or other electric forces in an active state. It was Mr. Fox * who first drew attention to the fact of the passage of currents along conducting strata beneath the surface of the earth. He detected their presence in the metalliferous veins of the mines of Cornwall. Since that time it has been well-established that such currents exist generally. From the Royal Observatory at Greenwich two wires are laid down, one to Croydon, the other to Dartford, and a suitable apparatus has been constructed for registering the earth currents flowing along them. We may, however, I think, safely assume that the effects produced by such causes will in ordinary cases be confined within narrow limits, although under special circumstances—viz. when the magnetic current flowing upon the surface of the earth, and the underground current which it sets in motion, tally to a certain extent in the direction in which they flow—a very different result may be brought about. Thus two places are found in the northern hemisphere which have an influence over so wide an area that they are regarded by some as magnetic poles. One of them is situated to the north of Canada, the

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* "Terrestrial Magnetism," p. 169.

† Ibid. p. 168.

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* "Terrestrial Magnetism," p. 180.

other in Siberia. Whether there are two corresponding places, or only one, in the southern hemisphere is not clearly made out. The information we possess is not exact enough to allow us to fix the latitude and longitude of these so-called magnetic poles. Between the one in North America and that in Siberia there is this difference: in the case of the former the needle points to it from every side, the local inflences are very powerful and appear to predominate over every other to a great distance around; in the latter case, in the midst of a wide district having an easterly declination, we have a pretty extensive locality with a westerly declination. The idea suggested by the circumstances of this last case is that the magnetic current which flows from the east to the west here escapes into the air (as no doubt happens also in the other place referred to), and circulating towards the west in the direction of the south pole of the earth, communicates to the magnetic current flowing upon the earth in these parts a southerly inclination, and makes the needle veer towards the west. We naturally look for an effect of this kind to take place in conformity with that which happens in the case of the magnet. In this escape of positive electricity into the air in the northern hemisphere having a westerly direction, and of negative electricity into the air in the southern hemisphere having an easterly direction, we have a magnetic influence which is of a general and not simply of a local character; and it may perhaps serve to explain the fact of the preponderance in degree, if not in extent, of the westerly over the easterly declination of the current in the arctic as well as the antarctic circle.

Have we any grounds for believing that there is a magnetic action through the upper regions of the air between the north and south poles of the earth? Instances are cited of auroras occurring in the northern and southern regions which seemed to correspond one with another. It does not of course follow that because the auroral lights in the two hemispheres are not visibly conjoined together there may not be a connection between them. We often see in the vacuum tube the positive and negative terminals in a glow, without any continuous stream of light passing from one to the other. On the other hand, it has to be admitted that the earth is, in comparison with its magnitude, very feeble in electric power; at all events, this is certain, that the aurora borealis and australis, which owe their origin to these currents of electricity passing into the air, exercise a powerful magnetic influence, which extends far beyond the regions in which they are visible. It has been observed before, in speaking of the action of positive and negative currents, that the former, when the current is a direct one, is more powerful in its effects than the latter; I may mention it here, as a fact in accordance with this rule, that the aurora borealis is, in point of brilliancy and power, superior to the aurora australis.

I have shown, I think, sufficiently how the normal direction of the earth's current may become modified in no inconsiderable degree by magnetic influences either of a local or of a more general character. But I have yet to consider the most important of the latter kind, viz. those which produce periodic variations. They are of three kinds, the diurnal, the annual, and the secular. I will speak of each of them in succession.

LECTURE XII.

PERIODIC CHANGES IN THE DECLINATION OF THE MAGNETIC CURRENT.

The variations, diurnal, annual, and secular, to which the magnetic current is subject.

THE diurnal variation of the current is very small, so small that the ordinary needle is not delicate enough to show it. It is different in different latitudes; almost nothing at the equator, it increases in amount in the intermediate zones, and decreases again as we approach towards the poles. The following instances will serve to show what is the extent of range which prevails in different latitudes:—At Singapore, lat. 1° 16′, the swing is under 2′; at London, lat. 51° 30′, it is about 10′; and at St. Petersburg, lat. 59° 57′, it is about 5′. Each place has its maximum and minimum range. If the place be in the northern hemisphere, the time of its maximum range occurs when the sun is in the northern signs of the zodiac, of its minimum range when the sun is in the southern signs of the zodiac. If the place be in the southern hemisphere, these times are reversed.

The mean diurnal variation for Kew, as recorded at its observatory, is as follows:*—About three in the morning the needle begins to veer eastward. At eight it has reached its farthest easterly point. From 8 a.m. to 1.30 p.m. it makes a sweep of about 10′ to the west. It then returns gradually to the east, the easterly deviation becoming a maximum about 11 p.m., when the needle falls back slowly to the point from which it started at 8 a.m. The changes here described for Kew are in a certain proportionate degree repeated over the whole of the northern hemisphere. We have the record of the diurnal variation of no place so far south as London is north of the equator. But we have observations made at the Cape, and at Hobarton, and at St. Helena, and it appears that the discrepancy which exists in the diurnal motion of the needle in the two hemispheres amounts to this, that, whilst during the early hours of the morning and the late hours of the evening the north end of the needle inclines in the northern hemisphere to the east, it inclines in the southern hemisphere to the west; and, whilst during the middle hours of the day the same end of the needle inclines in the northern hemisphere towards the west, it inclines in the southern hemisphere in the direction of the east.†

What is the explanation to be given of the above-mentioned facts? As no explanation obtaining any general assent has, as far as I am aware, yet been given of the phenomena connected with the diurnal variation of the current (the same thing may be said also of the phenomena connected with the annual and secular variations), I may venture to suggest a solution in harmony with that theory concerning the origin of the magnetic current which I am contending for.

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* Ferguson's "Manual of Electricity," p. 36.

† At any place near the equator where the sun is at one time to the north, at another time to the south of it—*e.g.* at Singapore—the same end of the needle points, according to the different circumstances of the case, at one time towards the east, at another time towards the west.

From what has been said above, it appears, first of all, that the magnetic current is set in motion and the needle is stirred long before the sun shows itself above the horizon. How can this be accounted for? By the fact of the chemical being of all the most refrangible rays of the sun. Upon entering the highest atmospheric strata they will be deflected, and will fall upon the earth a great deal earlier in the morning and later in the evening than the other rays of the sun. A current will consequently be generated by them corresponding in its direction to that given to them before reaching the earth. What that direction will be we have next to consider.

The needle, it has been said, deflects during the early hours of the morning and the late hours of the evening in the northern hemisphere towards the east, in the southern hemisphere towards the west. This means of course that the magnetic current which flows from east to west diverges somewhat in the former case towards the north pole, in the latter to the south pole. What is the cause of this? The rays which reach the earth by refraction before the sun has appeared upon the horizon, and even for some time after it has risen, will have travelled some thousands of miles almost horizontally through the upper regions of the air over parts of the earth which have the sun shining upon them. Now we know when the sun shines upon the earth in the torrid zone, which is exposed to its fiercest glare, the heated air mounting upwards divides into two currents, one of which flows to the north pole, the other to the south pole. The air of the upper regions above the earth is electro-positive in its character. Out of 10,500 readings taken at the Kew Observatory between January 1844 and July 1848, 10,170 indicated a state of positive, 324 a state of negative electricity. The chemical rays of the sun are also electro-positive. What then will be the mutual action upon one another of these two currents, both positive, one flowing to the west, the other, in the northern hemisphere, flowing to the north? The one will be deflected to some extent in the direction of the other. Hence in the northern hemisphere the magnetic current which flows from east to west, after descending obliquely through the air, will be found when it reaches the earth deflected in some degree in the direction of the north, and the needle will diverge towards the east. It may be urged perhaps that the sultry winds which blow unintermittingly from the tropics towards the poles, in proportion as they cool, gravitate towards the earth, and by the time they reach our latitude interpenetrate the lower atmospheric strata. This is true; but the atmosphere at the centre of the earth having a rotatory motion of greater velocity than it has in these parts, that which was a south wind blowing from the equator is converted into a south-west wind here, and, if it ever reached so far, would in the arctic circle be converted into a west, if not a north-west wind. In the greater part then of the torrid zone, where the heated air ascends almost in a direct line, the level rays of the sun passing through it will suffer very little deflection, and the declination of the needle will be hardly perceptible. In the temperate zones, where the upper current will be in one hemisphere a south or south-west wind, in the other hemisphere a north or north-west wind, the electric rays of the sun will be to some extent diverted, and the needle will be deflected in the former case to the east and in the latter to the west. This deflection of the needle will diminish along with the diminution of the upper atmospheric current as we approach towards either pole.

During the middle hours of the day the needle, as has been said, deflects in the northern hemisphere to the west, in the southern hemisphere to the east. How is the effect to be accounted for? In proportion as the sun rises higher in the heavens its rays will fall more perpendicularly on the earth, and will be less affected by the atmospheric strata through which they pass. The magnetic current will therefore gradually return to its ordinary course, and the needle will fall back to its mean position. The same cause will act in another way also towards bringing about the same result; for in proportion as the sun ascends higher in the heavens it will heat more intensely the surface of the earth within the tropics. The air in contact with the earth's surface will consequently become rapidly heated and mount upwards, whilst a lower current of air will rush in from either side towards the equator. This current of air—which is, as has been said, positively charged—sweeping over the earth's magnetic current, which flows from east to west, will deflect its course in some degree towards the tropics. Consequently the needle will deviate in some degree in the northern hemisphere towards the west, and in the southern hemisphere towards the east. No doubt the influence of this cause, though it will exert a certain force over a large portion of the earth's surface, will be everywhere extremely small; but it must make itself felt to some extent, and you must bear in mind the variation which we are seeking to account for is in itself extremely small, so small that the ordinary needle gives no indication of it whatever.

I proceed next to consider the annual variation of the magnetic current. It was discovered by Cassini in 1786, who found that for about three months in the year, viz. from the vernal equinox to the summer solstice, the north end of the needle moved steadily eastward, and that during the remaining nine months it moved at a slower rate westward, the excess of the westerly over the easterly movement representing the year's contribution to the secular variation. The amount of the year's contribution to the secular variation was at that time greater than it is at the present, when, as I shall have occasion to explain, we are approaching the highest point in the magnetic curve. In what is sometimes included in the annual variation, we have then two separate and distinct elements of change mixed up together, the one belonging more properly to the secular variation, to which I shall draw your attention later, the other appertaining strictly to the annual variation.

We are told that the diurnal and the annual variations differ from each other in this respect, viz. that in the case of the former the movement of the needle is of an opposite character in each hemisphere, whilst in the case of the latter it is in both hemispheres alike. At Kew, *e.g.*, the magnet deflects towards the east when the sun is north of the equator, towards the west when it is south. At Hobarton the deflections which the needle makes are in the same direction under the same circumstances. The annual variation is very small in amount, averaging at Kew from March 21st to September 21st 28″·95 to the east, and from September to March 29″·9 to the west. From comparing together the observations made at Kew, at Hobarton, at Cape Town, and at St. Helena, it appears that, though the annual variation is similar in direction in both hemispheres, it is different in amount in each particular place according as that place is nearer to or farther from the equator. At Kew the amount of the annual variation is 58″·86, at St. Helena it is 14″.

How are we to account for this annual variation of the current? It seems to me to be due to changes of a periodical character which take place in the earth's atmosphere, affecting its influence upon the magnetic current. It is an ascertained fact that the earth's atmosphere has a much greater electric intensity in winter than in summer. M. Quetelet, at the Royal Observatory at Brussels, carried on a series of observations relative to the state of the atmosphere, and found that its electricity attained a maximum in January, and after that diminished progressively until it reached a minimum in June, the electric tension in the former month being thirteen times greater than in the latter.* Now the atmosphere revolving with the earth from west to east must, to some extent at least, deflect the current which flows upon the earth's surface from east to west in an oblique direction. It is manifest, therefore, that the revolution of this atmosphere over a descending magnetic current (in our part of the world the magnetic current is a descending one) must have a greater power to depress it in the season of the year when it is more highly charged than in that when it is less so. Hence we may easily understand how it should come to pass that, in the northern hemisphere in which we are, the needle should deflect to the west when the sun is to the south of the equator, and to the east when the sun is to the north of it. But we are told that the needle moves in the southern hemisphere precisely the same way, *i.e.* to the west when the sun is south, and to the east when it is north of the equator. It would seem therefore that this explanation is inadequate. Of course, if the increase which takes place in the electric intensity of the air from the autumnal to the vernal equinox were due to the fact that the distance between the sun and the earth is diminished at that time, we should expect to find that a greater electric energy was generated simultaneously in both hemispheres, and that consequently the declination of the needle would be marked by the same character in both. We are, however, I think, bound to admit that the greater tension of the atmosphere during the winter months in the northern hemisphere is to be regarded, not as a consequence of the earth being at that time nearer in its orbit to the sun, but as due to the fact that a moist and cold atmosphere is a better conductor of electricity than a dry and heated atmosphere. Or, again, if in the northern hemisphere there were an absorption of positive electricity, and in the southern hemisphere an absorption, not of positive, but of negative electricity in the air, that fact might account for a similar movement of the needle taking place in the two hemispheres at the same time, notwithstanding the difference of season prevailing in each. But, though I have not come across any statement relating to this matter, I take it for granted that the earth's atmosphere, revolving as it does everywhere in a direction contrary to the positive current, will be everywhere electro-positive in its character. If, then, I attribute the annual variation of the needle to the changes of the season of the year affecting the electricity of the earth's atmosphere, how do I meet the fact that the needle turns, in both northern and southern hemisphere alike, to the east when the sun is above and to the west when it is below the equator. My answer to this is, that if once it be proved to be a fact that the needle turns in one and the same direction in both the northern and the southern hemisphere when the sun is above, and in the contrary direction when the sun is below the equator, it will undoubtedly be necessary to look for a different cause from the one I have named in order to explain the annual variation. But, as far as I am aware, no such proof has as yet been given. Particular facts have been adduced, and a general conclusion has been drawn from them; but it seems to me they admit of having an altogether different interpretation put upon them, an interpretation which lends support to instead of overturning the theory I have put forward to account for the semi-annual changes of the magnetic needle.

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* Noad's "Student's Textbook of Electricity," p. 69.

At Kew the needle turns towards the west when the sun is south, towards the east when the sun is north of the equator. The reason of this, I have said, is because the earth's atmosphere, which revolves over the magnetic current obliquely from west to east, is more powerfully electric in the winter than in the summer months. At Hobarton the needle moves in the same way, *i.e.* to the west when the sun is south, to the east when the sun is north of the equator, although it is summer at Hobarton when it is winter at Kew. But then we must bear in mind that at Kew the magnetic current is a descending current, at Hobarton it is an ascending one. At Kew the atmosphere in passing over the current presses it down, and, as in the winter months it presses it down in a greater degree, it makes the needle deflect during those months towards the west. At Hobarton, on the other hand, the atmosphere in passing over the current tends to raise it up, but as it does so in a less degree in the summer than in the winter months, it makes the needle deflect less to the east, and therefore equivalently more to the west, during the summer than during the winter months. Hence we see how it is that when the sun is below the equator the needle moves in the same direction both at Kew and at Hobarton. This similarity in the movement of the needle at two places, one of which is in the northern, and the other in the southern hemisphere, is not in any way therefore inconsistent with the theory I have put before you, if at one place the current is an ascending current and at the other a descending one. But we are told that at St. Helena, and also at Cape Town, the needle turns to the west when the sun is south of the equator, and to the east when the sun is north of the equator, in the same way as it does at Kew, although at St. Helena and at Cape Town the magnetic current is not an ascending but a descending current. We have reason to believe, however, that the movement of the needle at these two places is, owing to local influences, abnormal. The island of St. Helena is in that part of the Atlantic where the trade-winds blow steadily from the south-east. Now as these winds blow with much greater strength when the sun is north than when it is south of the equator, and as from the direction in which they blow they tend to raise the magnetic current, they will have the effect of turning the needle towards the east at St. Helena at the same time that it is turned towards the east at Kew. The movement of the needle at Cape Town may be explained in a similar way. The magnetic current, after traversing the Indian Ocean in a descending line, crosses the Mozambique Channel before it passes over the extreme south part of Africa. Its course cannot then but be affected in some degree by the monsoon which blows between the Mozambique coast and Madagascar, for the six months from April to October from the south-east, and for the six months from October to April from the north-west. During the former six months, which correspond with the summer at Kew, the descending current is raised and the needle veers towards the east; during the latter six months, which correspond to the winter at Kew, the descending current is depressed and the needle turns towards the west. Thus the needle moves in the same direction, though from different causes, at Kew, at St. Helena, and at Cape Town. I have called the movement of the needle at St. Helena and at Cape Town abnormal, because it is not in accordance with what I regard as the general law applying equally to the northern and the southern hemisphere, viz. that the revolving atmosphere exerts a greater force in winter than in summer in depressing the current where it is a descending one, and in elevating it where it is an ascending one. Yet even in these cases which I call exceptional it remains true that the annual variation of the needle is the consequence of the changes which take place in the different seasons of the year affecting the earth's atmosphere, and so affecting its action upon the magnetic current. This explanation must be looked upon as tentative and conjectural. I have not that acquaintance with the facts which relate to the variation of the needle in different parts of the world which is needed in order to be able to arrive at a certain conclusion.

It is stated, as you have seen, that the annual variation at any particular place is greater or less in amount according as that place is farther from or nearer to the equator. At Kew it is 58″·96, at Cape Town 48″, at St. Helena only 14″. Colonel Sabine considers that this difference in different places in the amount of the deflection of the needle may, in part at least, be occasioned by the difference in the amount of the antagonistic force of the earth's magnetism which tends to retain the magnet in a mean position in opposition to disturbing causes. This antagonistic force of the earth's magnetism is said to be approximately 5·6 units at St. Helena, 4·5 at Cape Town, and 3·8 at Kew. It may be, indeed, that the total force of the earth's magnetism is not in reality greater at the equator than it is at the poles. At one pole there is a preponderance of positive magnetism, and at the other pole a preponderance of negative magnetism, whilst at the equator these two forces are in a state of equilibrium. Now a needle which has at the equator both ends bound by an equal force will not so easily be moved from its position by any extraneous influence which is brought to bear upon it, as a needle which is placed near one of the poles of the earth, where its force, even though it should be greater in amount, is all concentrated upon one of its ends.

We come now to the secular variation, the one which most of all concerns us, because, besides being very much greater in amount than either the diurnal or annual, it appears at first sight to present an almost insuperable difficulty in the way of our acceptance of any theory which connects the course of the magnetic current with the sun's path upon the earth. The following table, which shows the progressive magnetic changes which have taken place at London from the year 1580 to the year 1865, will enable you to understand the extent to which these changes have gone, as well as the difficulty which has to be cleared up. As I deal only with the broad features of the case I need do no more than allude to the fact that discrepancies of a minor character are found to exist between this and other similar tables, and that some doubt is thrown upon the accuracy of the earliest recorded observations.

East declination		**Zero**	**West declination**					
1580	1622	1660	1692	1730	1765	1811	1850	1865
11° 15′	6°	0	6°	13°	20°	24° 41′	22° 30′	21° 6′

From this table we see that London had at one time an easterly and has now a westerly declination, and that from 1580, when the needle pointed farthest to the east (we have no earlier observations recorded), to 1818 when the needle pointed farthest to the west, *i.e.* during a period of 238 years a variation took place of 26° in the direction of the current. At Paris, the declination was, in 1580, 11° 30′ east, and in 1814, when the maximum westerly declination was reached, 22° 34′ west, making in the space of 234 years a variation in the current of 34°. Can these changes be in any way accounted for? I will begin my answer to this question by showing that, if the hypothesis of a progressive westerly movement of the path of the magnetic current upon the surface of the earth be admitted, these changes may be easily explained. I will then set before you the ground we have for admitting this hypothesis, which I think will be found satisfactory.

The needle, as we have seen, pointed at London, in the year 1580, 10° 15′ east. In 1660 it was due north. From that time it has continued to point to the west of the north pole. This means that at London before 1660 the magnetic current was an ascending current, after 1660 it was a descending current, but at that particular date it was neither ascending nor descending, but was at the turning point, *i.e.* either the highest point which the current reaches or the lowest point to which it goes in the circuit which it makes round the earth. These two turning points correspond to the two lines of no-variation which run from north to south, upon which the needle points due north. The turning point upon which London stood in 1660 I take to be the lowest point of the current. This point has from that time travelled slowly towards the west. If we look along the same latitude—the line of no-variation, as I have said, reaches from north to south—we shall find it at the present time in the north-east part of Lower Canada; whilst London, after crossing the lowest point of the current in 1660, has gradually advanced eastward on the line of the current, until, having passed the middle and most curved part, where the needle points farthest to the west, it is now far on its way to the highest point of the current, where the needle will again point due north, and afterwards begin to point once more to the east. In order that this variation of the needle should take place at London, it is not necessary that the position of London or the direction of the magnetic current should undergo any real change in themselves; it is sufficient that the turning points of the current, or, which is the same thing, that the lines of no-variation should have a progressive movement to the west. For suppose the lowest point of the current, upon which London stood in 1660, carried forward a degree towards the west, the current which reaches that point will now flow west of London, and London will be reached by a current which has its lowest point below the lowest point of the former current. And as this line of no-variation progresses step by step farther away from London to the west, so London will occupy step by step a higher position on each succeeding current which reaches it, until, the line of no-variation on which London stood in 1660 having gone half-way round the globe, the other line of no-variation will have taken its place, and London will have reached then the highest point of the current. It is to that point that London is now slowly approaching, and at which, if nothing occurs to arrest the onward movement of the path of the magnetic current towards the west, we may expect it to arrive in less than another century.

You see then that, once we have the hypothesis allowed that the magnetic current in its circuit round the earth moves more and more to the west, it will be possible for us to account for the secular variation which takes place in the declination of the needle, and, as will appear later, for the secular variation which takes place also in its dip. We have next then to consider what independent proof can be adduced in support of this hypothesis.

In the first place, this hypothesis comes before us as being in accordance with well-ascertained facts. Thus we are told* that by a careful analysis of the observations recorded at long intervals of time, the nodes, or points of intersection of the magnetic and terrestrial equators, have a slow westerly movement. Again, if we compare the magnetic chart published by Hansteen in 1787 with that published by Sabine in 1840, we shall find that during the intervening time nearly the whole area of both eastern and western declination had been carried a certain distance towards the west. Thus in Hansteen's chart we have one line of no-variation running down on the east side of Hindostan, the other line of no-variation skirting the east coast of Brazil; whilst in Sabine's chart the former line is to be found on the west side of Hindostan, the latter descends through the middle part of Brazil. During the same period we find that in the northern hemisphere the eastern line of no-variation had gained upon Europe, and that in the southern hemisphere the western line of no-variation had advanced a considerable distance through the Australian continent. No doubt this comparison, if it were brought down to the present time, would be still more effective, but I have not the materials necessary for doing so at hand.

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* "Rudimentary Magnetism," p. 266.

I pass on, therefore, to the further question which presents itself to us, whether any reason can be assigned why the path of the magnetic current should thus continually swerve towards the west? It seems to me that this gradual transference of the course of the magnetic current in a westerly direction is a necessary consequence of the fact that the current flows round the earth from east to west in a line corresponding to the plane of the ecliptic, whilst the earth at the same time rotates from west to east in a line corresponding with the plane of the terrestrial equator. If the earth did not rotate at all, or if it rotated in a line corresponding to the magnetic equator, in either of these cases no change would take place in the course of the magnetic current. But since the earth turns from west to east in a line parallel to the terrestrial equator, whilst the current makes the circuit of the earth from east to west in a line parallel to the magnetic equator, it is plain that the current, in descending from the highest point of its circuit to the lowest, must be carried as much farther to the west as the earth has in the intervening time moved from west to east; and in like manner that the current, when ascending from its lowest to its highest point on the surface of the earth, will be carried as much to the west as the earth has during that time moved round to the east. It is true the progressive movement towards the west which the path of the current will be able to make whilst performing one single circuit round the earth may be indefinitely small; but it is certain some movement in that direction must take place, and since this movement will go on whilst the current makes circuit after circuit upon the surface of the earth until it reaches the north pole, and since this same process will be repeated day after day and year after year, it is manifest that, however small may be the beginning of this movement, however insensible its growth, it must in course of time come to be very considerable, and is quite sufficient to account for that secular variation which takes place in the declination of the needle.

This slow westerly movement which marks the progress of the magnetic current round the earth is not, however, strictly uniform in any one place from year to year, neither does it proceed in different places at the same rate. Many causes operate in bringing about this inequality in the progressive movement of the current in different places and at different times. I can do no more than touch upon some of the principal ones. An epoch of about ten years brings with it the recurrence of a number of spots upon the surface of the sun. They are accompanied by, if indeed they may not be regarded as the cause of, an outburst of magnetic energy upon the earth, as shown by the prevalence in an unusual degree of auroral and of other magnetic phenomena. Now the development of increased magnetic energy upon the earth will not of itself affect the direction in which the current will flow upon it; but the fact that these spots are seen to pass athwart the disk of the sun in a somewhat different direction at different times gives us reason to infer that the current which sweeps round the body of the sun, or, it may be, the photosphere which rotates with it, varies in its course to a certain extent, and that consequently the course of the current which it generates upon the earth will to a certain extent vary in like manner.

The most curved part of the line of the magnetic current, whether it be ascending or descending, will be midway, or nearly so, between the two extreme points. The needle there points farthest to the east, or to the west, as the case may be. London stood there in 1818, when the needle attained its maximum declination, 24° 41′ west. This curvature in the line of the current seems due to the influence which the charged atmosphere, rotating together with the earth, exerts upon the current, which flows in an oblique direction beneath it. It is for this reason probably that the change which takes place year by year in the declination of the needle is least when the needle is at or near one of the turning points of the current, and is greatest when the needle is intermediate in position between them.

But why is it that the lines of no-variation which mark the highest and the lowest point which the current touches in each of its circuits round the earth, instead of being perpendicular to the magnetic equator, deflect to the north-west? It has already been stated that the rotation of the earth upon its axis causes the magnetic current to diverge in the direction of the west so long as it continues to flow upon the earth, and, as it receives constantly a new influx of magnetic force, it will continue to flow on until it reaches the north pole. We are thus able to explain that gradual divergence towards the west which takes place in the two lines of no-variation as they run from south to north. But, besides many irregularities of less importance, there are one or two striking deviations in the course of these lines which I do not know how we can account for, except we attribute them to the disturbing effect produced by local magnetic influences, which proceed, as we have already seen, either from the ferruginous or volcanic nature of the soil, or from underground currents of electricity, or from powerful atmospheric currents blowing continuously in one particular direction. You will see marked down in Sabine's magnetic chart a very abrupt divergence of the line of no-variation along the coast of the island of Java in the Indian Ocean. Can we account for this? It is due principally, I think, to the volcanic character of the island; in part, however, to the combined action of the charged atmosphere revolving from west to east and of the periodical winds blowing in those parts. In other words, both subterranean and atmospheric influences are here present. Referring to Johnstone's Atlas, you will find a volcanic ridge marked down as lying in the very track of the magnetic current. Again, we know that whenever the revolving atmosphere meets with no opposing current of air it cannot fail after some time to produce a certain effect upon the course of the earth's magnetism. Now in this particular case, where the volcanic influences of the coast of Java deflect the magnetic current to the east, not only does the revolving atmosphere during the six months when the sun is south of the equator meet with no opposing current of air, it meets on the contrary with one which has a direction very similar to its own; for during this particular time of the year a north-west monsoon blows over the sea of Java, which we are told * is the consequence of the vast tract of the country of New Holland becoming heated by the presence of the sun, and the colder air of the ocean rushing in to take the place of the rarefied air, which mounts upwards. It is true that when the sun passes to the north of the equator this north-west monsoon is succeeded by the south-east trade-wind, which blows over the Javan Sea for the ensuing six months with little interruption. But, in the first place, the effect produced upon the course of the magnetic current by this south-east wind, which acts in opposition to the revolving atmosphere, cannot equal the effect produced by the north-west monsoon, which acts in conjunction with the revolving atmosphere. Again, during the six months when the sun is north of the equator, Hindostan, Siam, and other adjacent countries become heated in the same manner as New Holland does when the sun is south of the equator. The colder air rushes in from the north of the Indian ocean to fill up the vacuum created by the rarefied air ascending up-

Popular Encyclopædia," article *Wind.*

wards, and a south-west wind is there produced. This south-west wind, blowing for six months over the descending magnetic current in the higher part, and a south-east wind blowing at the same time over the descending current in the lower part of the Indian Ocean will tend to neutralise one another, and so leave the effect produced upon the current during the other six months of the year unaltered. The consequence will be that if the line of no-variation has still here, as well as elsewhere, a westerly movement, arising from the rotation of the earth from west to east, that movement will be less here than elsewhere, and this inequality in the movement of the current going on year after year must end by breaking up, for a time at least, the unity of the magnetic system of the two hemispheres.

LECTURE XIII.

THE INCLINATION AND THE INTENSITY OF THE MAGNETIC CURRENT.

The magnetic and geographical equators not the same—The general law of the inclination or dip of the needle—The annual and secular variation to which it is subject—The intensity of the magnetic current—The variations, secular and annual, it undergoes.

I AM going now to speak of the inclination or dip of the needle, and of the annual and secular variations to which it is subject. It is necessary, however, that we should in the first place understand how the earth's magnetic equator is situated in relation to its geographical equator.

In accordance with the theory which connects the pathway of the magnetic current upon the earth with that of the sun, we should expect to find the magnetic current ascend on one side above and descend on the other side below the terrestrial equator; not, however, to the full extent of twenty-three and a half degrees, because, though the sun's path does rise and fall as much in relation to the equator, the sun itself, as has been said, is inclined in the same direction as the earth nearly seven and a half degrees. The magnetic current, being generated by the rotation of the sun, ought to confine itself within about sixteen degrees of a line parallel to the equator. It is found that it does do so. Duperrey, to whom we are indebted for a very careful and able investigation of this problem, has given us a chart which represents according to the most trustworthy researches the course of the magnetic equator. Starting from its eastern node, or the point where it intersects the terrestrial equator, in long. 5° 40′ east, he traces it to its highest point about fifteen degrees north of the equator, near the Red Sea. Thence he follows it through the Indian Ocean, the south of Hindostan, the north of Borneo, and so on until it crosses once more the terrestrial equator in long. 178° 20′. The other half of its course south of the equator is, he assures us, much more like the first half than was generally supposed. Throughout the greater part of the entire circle the line is tolerably regular, but in some places, as for instance where it passes through clusters of coral or volcanic islands in the Pacific Ocean, its windings are interminable, and its main direction is not easily recognised.

A needle suspended over a magnet inclines, as you know, neither to one end nor the other so long as it rests over the equator, or that line which is equidistant from the two poles of the magnet. But in proportion as the needle is brought nearer to one or other of the poles it inclines in a greater degree to that pole, until, when it actually reaches the pole, it stands vertically over it. In like manner, a needle suspended over the magnetic equator of the earth stands level, inclining neither to the one side nor to the other. But the farther the needle is removed from the equator towards one of the poles, the more it dips down in the direction of that pole, until, when it reaches the pole, it stands vertically over it.

There are, however, certain periodical variations which take place in the inclination of the needle. The diurnal changes cannot be said to be as yet clearly made out; we need not stop, therefore, to consider them. The annual and secular variations are more accurately known, and admit, I think, of being satisfactorily explained. The dip is less in summer than in winter. From observations made at Kew during six years it was found to be 0′·27 less from April to October, and 0′·27 more from October to April than is due to the mean value.* What is the cause of this? The sun ascends above the equator in the summer and descends below the equator in the winter twenty-three and a half degrees. It is true that the course of the magnetic current upon the earth, and consequently the position of the magnetic equator, are not affected by the alteration of the sun's position at the different seasons of the year. If at Kew the needle were nearer at one time of the year to the magnetic equator than it was at another by forty-seven degrees, or, making a deduction on account of the sun being inclined nearly seven and a half degrees in the same direction as the earth, as much as thirty-two degrees, the variation in its dip would be very much greater than it is at present. But though the magnetic equator does not change its position, the magnetic poles do. The earth, as I have already had occasion to point out, is not in itself a magnet, but it is magnetically excited by the action of the sun. The position of its poles will depend therefore upon the distance to which the magnetising effect of the sun's power reaches. Now in this hemisphere the magnetising effects of the sun's power will extend farther to the north in the summer than in the winter. And as each place has its own pole, in each place situated in the northern hemisphere the needle will dip proportionately less in the summer than in the winter. The amount of the needle's variation is not, however, every year alike. When the sun puts forth greater magnetic power, which it does at the time of the periodic recurrence of a larger number of spots upon its disk, it makes its influence felt farther on either side of the equator, and the semi-annual inequalities in the dip of the needle are consequently greater.

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* "Rudimentary Magnetism," p. 298.

This variation which I have endeavoured to account for belongs strictly to the year. There is another variation which, going on year by year, constitutes what is called the secular variation in the dip of the needle. Let me begin by putting before you a table representing the changes which have taken place at London, as recorded by different observers in the *Philosophical Transactions*.

Secular Variation in the Dip of the Needle.

1576 71° 50′	1676 73° 30′	1723 74° 42′	1790 71° 53′	1800 70° 35′
1821 70° 3′	1830 69° 38′	1847 69°	1863 68° 4′	1871 68° 2′

Thus we see that the inclination when first observed by Norman in 1576 was increasing, that it reached its maximum in 1723, and that from that time it has gone on decreasing at a variable rate. This secular variation in the dip of the needle has a manifest connection with the secular variation in its declination. We have seen that the line of the magnetic equator, which rises on one side sixteen degrees above and falls on the other side sixteen degrees below the terrestrial equator, and in parallel direction to which the magnetic current flows everywhere on the earth, has a slow westerly movement. In 1723 London stood over the lowest point of the line; it was then at the greatest distance from the magnetic equator, and the needle had reached its maximum inclination. Before 1723 London was advancing slowly towards this turning point of the equatorial current, or, to speak more accurately, this lowest point of the equatorial current was advancing slowly towards the meridian of London; the inclination of the needle was therefore increasing at London each year. Since 1723 London has been moving farther and farther away from that lowest point. The inclination of the needle has therefore decreased in proportion, and will continue to decrease until London stands over the highest point of this current, when it will have attained its least distance from the magnetic equator and its minimum dip, after which the inclination at London will begin once more to increase. Before, however, this event occurs more than another century will have to pass away, unless some great change should take place which should interfere with the slow rate at which the line of the magnetic current at present moves westward.

But was it not said that London stood upon the lowest turning point of the magnetic current about the year 1660, when the needle pointed due north? How then can this statement be made to agree with the fact that London was in 1723 at its farthest distance from the magnetic equator, the dip of the needle having continued to increase down to that year?

The movement of the declination and inclination needle is produced by the magnetic current acting under different circumstances. The magnetic current flows over the whole surface of the earth in a direction corresponding to the magnetic equator, and the declination needle rests everywhere upon it at right angles. As the magnetic equator does not coincide with the terrestrial equator, but is inclined to it, the declination needle points either to one side or to the other of the north pole, according as the current is ascending or descending. Only at the turning points, where the current is neither ascending nor descending in relation to the earth's equator, does the needle point due north. But, as we have seen, the higher in north latitude the current flows upon the earth, the farther, in consequence of the earth's rotation to the east, are the turning points of the current deflected to the west. In 1660, when London was upon the lowest point of the current in its own latitude, those places which stood on the same geographical meridian north of London had already passed the lowest point of the current in their latitude, whilst those places which were on the same meridian south of London had not yet come to that point. London then was far from being at that time vertically over the lowest point of the magnetic equator.

The inclination needle is usually supposed to point to the magnetic pole by attraction because, being moved farther and farther from the equator, it dips more and more, until, when it reaches the pole, it stands vertically over it. I think myself it is more correct to say that the movement of the needle when suspended over the earth, and in like manner the movement of one magnet when suspended over another magnet, is the consequence of the reciprocal action which takes place between the lines of force which surround the two bodies. For there is, alike in the case of the magnet and of the earth, a current passing from every part of their surface into the air and circulating round them; and this charged atmosphere serves also as a medium which connects together the opposite electricities of the magnet and of the earth on the two sides of their equator.

But in whatever way the movement of the needle may be caused, it is an undisputed fact that the amount of the dip marks the relative distance of the place from the magnetic equator. Hence it is certain that London did not stand vertically over the lowest point of the equator till long after it had passed the lowest point of the magnetic current which flows round the earth in its own latitude. And since the dip of the needle continued to increase at London for a considerable time after the declination of the needle had changed from east to west, so we may conclude that the dip of the needle will continue for the same reason to decrease long after the needle shall have begun to point once more to the east.

I have to speak next of the intensity of the magnetic current, and of the secular and other periodical changes to which it is subject. The earth must derive its magnetic intensity from the same source from which it derives its magnetic character, viz. from the sun. But the magnetic intensity of any particular place will be greatly modified by local circumstances, and by causes having a more widespread influence. As in the case of the needle, so in like manner in respect to the earth we should expect to find the magnetic force least at the equator, greatest at the poles, because at each pole we shall have, in addition to the positive or negative magnetism which is generated in that part of the globe, the positive or negative magnetism, as the case may be, which is generated in other parts of the globe, which will flow round the earth until it reaches that part. The proportion between the force of the current at the equator and at the pole is as 1 to 3. We are told that the lines of equal intensity, though running for the most part in the same direction as the lines of equal dip, are not coincident nor parallel with them, and that, in like manner, the line of least intensity is not the same as that of the magnetic equator. We can well understand that local influences, which are more powerful on the land than on the sea, will affect this as much as, if not more than the other elements of magnetism. Again, we know that the line of the magnetic equator is not itself a fixed stationary line, but one which is always moving along slowly to the west, whilst the rate at which the magnetic current travels westward differs in different parts of the earth. It may perhaps be found that the operation of these causes is sufficient to account for the discrepancy which is represented in our charts as existing between the lines of equal dip and of equal intensity. Certainly the place to the west of the island of St. Helena where Erman registered the lowest degree of intensity he had anywhere met with, viz. 0·743, was at the time when he sailed over it either upon or very close to the line of the magnetic equator.

The amount of the secular change in intensity is not yet, according to Hansteen, determined. It is known, however, that the intensity has been for a long time diminishing in Europe,* whilst it has been increasing in Siberia and in the greater part of Asia.† Sir James Clarke Ross concluded, from observations made on board the *Erebus* when, in 1839, he sailed to the Antarctic Ocean, that the line of least intensity had advanced considerably northward.

We have seen that in 1723 London stood over the lowest point of the magnetic equator. From that time therefore the whole of Europe has been gradually approaching nearer to the equatorial line, and its magnetic intensity has been consequently diminishing; whilst nearly the whole of Asia, having passed the highest point of the magnetic equator, is receding farther and farther from the equatorial line, and is consequently increasing in magnetic intensity. At the same time also the lowest point of the magnetic equator had begun to cross the Atlantic Ocean, so that, when Sir James Clarke Ross passed over the magnetic equator in 1839, he passed it in a more northern latitude than when he crossed it before.

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* "Terrestrial Magnetism," p. 159.

† "Student's Textbook of Electricity," p. 135.

But though the total magnetic force decreases the nearer we approach to the line of least intensity, it is not so in regard to horizontal intensity. A dipping needle oscillates faster at London than at Calcutta, because the total intensity is greater at the former than at the latter station. But with the compass-needle it is the reverse, from the horizontal intensity being, it is said, greater at the latter than at the former station. I have suggested that the reason of this may be that at the equator the horizontal needle has its magnetic force equally distributed over each end, whereas the nearer we approach to either pole the more is the force accumulated at one end. We are not surprised therefore to learn that, whilst the total intensity is gradually declining throughout Europe,* the horizontal intensity is increasing.†

The annual variation gives a maximum in December, a minimum in June, the difference being in the northern hemisphere about 0·0353. I have already had occasion to observe that although the line of the magnetic equator does not shift its position at different seasons of the year absolutely, yet it does so relatively, inasmuch as in our hemisphere any place is brought nearer to the pole in mid-winter, when the sun is twenty-three and a half degrees below the equator, than it is at mid-summer, when the sun is twenty-three and a half degrees above the equator. The nearer any place is to the pole, the farther it will be from the equator relatively, and the greater therefore will be the dip and the intensity of the current. The fact of the intensity of the magnetic current being, like that of the electricity of the atmosphere, greatest in winter, least in summer, lends support to the view that they are in some way connected one with the other. There can be little doubt that such is really the case. If the magnetic current is at one time more intense than at another, the atmosphere revolving over it must be affected thereby in some degree, although, as I shall have occasion to point out, there are other causes also which influence the electric state of the atmosphere.

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* "Rudimentary Magnetism," p. 276.

† Ferguson's "Manual of Electricity," p. 34.

I pass over the consideration of the diurnal variations of the intensity of the magnetic current for the same reason which I have given for omitting the consideration of the diurnal variation of its dip. It has not been satisfactorily made out what they are; or, if in particular cases the amount of diurnal changes which take place has been ascertained, it is not at all known how fár they depend upon local causes, how far they are attributable to any general law.

I have dwelt long upon the elucidation of different questions relating to the direction of the magnetic current upon the earth, and the variations to which it is subject, because I considered it of great importance to show that they present no obstacle in the way of our acceptance of the theory for which I am contending; but that, on the contrary, this theory is the only one which is capable of clearing up the difficulties with which they are surrounded on every side. About the soundness of the principles upon which I have attempted the solution of the questions which have here been brought before us I have no doubt, but I do not pretend that no exception can be taken to my application of them.

LECTURE XIV.

ATMOSPHERIC ELECTRICITY—LUNAR MAGNETIC INFLUENCE.

Whence does the atmosphere derive its electricity?—What are the variations to which it is subject?—Whence does the moon derive its magnetic influence?—What effect does it produce upon the earth's current?

I AM going to speak first of atmospheric electricity, touching briefly upon its character, origin, and its annual and diurnal variations. I shall consider afterwards the lunar magnetic influences which make themselves felt on the earth and produce diurnal changes in the current which flows over its surface. My object is to show that the phenomena relating to these, as well as other forms of magnetism, are in harmony with that theory which has been put before you concerning the nature of magnetism.

It is an ascertained fact that the earth's atmosphere is, as a rule, in a positive electric state, and that the higher aerial strata are so in a still greater degree than the lower. How does this happen? The sun is in a positively electrified state. The electricity which it transmits to the earth is therefore of the same character, and will, it must be admitted, to some extent at least, affect the air through which it passes before it reaches the earth. But just as heat, which is transmitted directly from the sun to the earth by the ethereal medium which connects the two bodies together, affects only in a very slight degree the temperature of the air, which derives its heat almost entirely by radiation or convection from the heated surface of the earth, so the same thing happens in respect to the electricity of the air, which is derived principally, though not perhaps exclusively, from the electrically excited surface of the earth. But how comes it then that, whereas the surface of the earth is, owing to the inductive power of the sun, negative rather than positive in its character, and whereas negative, therefore, not positive electricity must accumulate upon all its salient points and prominent ridges and discharge itself into the air, the air nevertheless should be found positive in its electric character? The reason of this is because the magnetic current which is transmitted from the sun to the earth flows upon the earth's surface from east to west, whilst the atmosphere revolves over the magnetic current in the opposite direction, *i.e.* from west to east.* Now as one at least of the elements of which the atmosphere consists is eminently magnetic, viz. the oxygen, a certain portion of the earth's current will necessarily be drawn up into the atmosphere, and then continue to revolve round the earth in ever-widening circles until it reaches the farthest limits of the earth's atmosphere. Both positive and negative electricity are present on the earth's surface. Both are present also in the atmosphere. And hence a conflict arises from time to time between these opposite electricities, producing, *e.g.*, violent thunder-storms and tornados in the equatorial regions, the auroral lights in the polar regions, and innumerable other electrical phenomena in all parts of the world. But these two electricities are not present in the atmosphere in the same or in like proportions. Beccaria has remarked on the rare occurrence of negative atmospheric indications. During a period of fifteen years he recorded the electrical state of the atmosphere negative only six times.* Quetelet carried on observations at Brussels upon the electricity of the atmosphere during four years and a half, and during that time he registered the state of the atmosphere as negative only twenty-three times, and these indications either preceded or followed rain and storms. A series of electrical readings taken at the Kew Observatory about the same time gives similar results. They prove further that a low state of positive electricity prevails in serene weather. On most of the occasions when high electric tensions were observed the presence of a fog occurred. In the majority of the instances in which negative electricity was exhibited, one or the other of these features was observed, either there was the falling of heavy rain or cirro-strati and cirro-cumuli hung in the air, these clouds contributing, as was supposed, to the development of the electricity observed.

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* I state here what I consider to be the principal cause of the positive electricity of the atmosphere; I do not mean at all to say that there are not other causes also, *e.g.* induction proceeding from the negative electric state of the earth.

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* "Student's Textbook of Electricity," p. 70.

It is highly probable that positive electricity is taken up by the revolving atmosphere in pretty nearly all states of the weather, but not to the same extent when the air is dry as when the air is moist. The presence of aqueous vapours in a condensed form in the air must serve to facilitate the escape of magnetism from the surface of the earth, in the same way as moisture in the air of the room carries off the fluid almost as fast as it is collected upon the prime conductor of an electric machine. We may understand then how it is that electricity prevails in a low state in the atmosphere in fair weather, and in a higher degree in foggy weather. We are told further that negative electricity is found to prevail principally on these two occasions, viz. after a heavy fall of rain and when non-electric clouds hang in the air. In the first of these cases we may suppose that the positive electricity which is taken up by the revolving atmosphere is attracted by the raindrops, and is brought down again to the earth by the falling of these drops. It is probable also that, these raindrops being themselves the result in the first instance of a chemical combination of hydrogen and oxygen gases, and next of an agglomeration of particles of vapour held in suspension by the atmosphere, their formation has not been effected without the absorption of a certain quantity of the free electricity which has escaped into the air. In the second case, it may be that as overhanging buildings, which are of course of the same character electrically as the ground on which they stand, neutralise the air between the ground and them, so in like manner overhanging strata of clouds, when they are not thunder-clouds or positively charged, produce a similar effect upon the air between them and the earth.

Let me proceed next to consider the annual and diurnal variations which have been observed in the atmosphere. It has been stated already that the electrical tension of the atmosphere is considerably higher in winter than in summer. In connection with this fact it is to be noticed that, whilst the proportion existing between the different constituents of the air remains the same, the density of the air is greater in colder than it is in hot weather, and that the oxygen element in the atmosphere must exert on this account more attraction upon the magnetic current in winter than in summer. Moreover, the atmosphere holds the moisture which floats in it in a more condensed form in the winter than in the summer months, and a general correspondence has been shown to exist between the months which are characterised by the greatest humidity and those which exhibit the highest electric tension.*

The diurnal changes differ to a certain extent in different places, and at the same place in different seasons of the year, in consequence of the change which takes place in the hour of the sun's rising and setting.

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* "Student's Textbook of Electricity," p. 69.

The following time-table, derived from observations made during a lengthened period at Kew, represents approximately the daily variations to which the electricity of the atmosphere is subject in these parts; and it may be looked upon as exhibiting what, under certain modifications, takes place everywhere else. The hour of minimum tension is 2 a.m. A gradual rise takes place from that time until 6 a.m. Between the hours of 6 and 8 a.m. a rapid rise occurs, the tension being nearly doubled. It continues to increase gradually until 10 a.m., when a maximum is passed; after which it gradually declines until 4 p.m., the epoch of the diurnal minimum as contradistinguished from the nocturnal minimum. The tension then rapidly increases until 8 p.m., and at 10 p.m. passes another maximum rather above the maximum of 10 a.m. From 10 p.m. to midnight the diminution of tension is enormous. The midnight value continues to diminish slowly up to 2 a.m., the epoch of the principal minimum.* The foregoing table represents the summer range. In winter the amount of tension is much greater than in summer: the minimum is at 4 a.m., rising gently to 6 a.m., and rapidly to 10 a.m., the forenoon maximum; then gradually sinking to 4 p.m., the afternoon minimum; and again rapidly rising till 8 p.m., the epoch of the evening maximum, the fall from which to midnight is enormous.

I will confine my remarks to the summer range. They can easily be applied to the different seasons of the year. The earth's current, I have said, owes its origin to the action of the sun. Now the sun rises in summer in our latitude about 4 a.m., but its chemical rays, which are more refrangible than rays of light and of heat, reach the surface of the earth before 2 a.m., from which time the magnetic current gains new force, and the revolving atmosphere absorbs a proportionately larger quantity of electricity. At 6 a.m. the mists begin to be drawn up from the earth by the heat of the sun. At first invisibly, and afterwards in a more condensed form, they continue rising, and serve as a conductor whereby the current ascends more freely into the air. Between the hours of 6 and 8 a.m. the electric tension of the air becomes doubled. It continues still to increase, though more slowly, till 10 a.m. From this time, the air having become dried, and therefore not so good a conductor, and being more rarefied, in consequence of which the oxygen of the air exerts less attraction upon the magnetic current, a gradual diminution of its electric tension takes place up to about 4 p.m. No sooner, however, does the moisture absorbed during the day into the atmosphere begin, in consequence of the cooling of the air, to condense and descend to the earth than the current once more freely ascends into the air, and a second maximum is reached, about 10 p.m. in summer and 8 p.m. in winter. Then the chemical rays of the sun cease altogether to fall upon the earth, and an enormous diminution of electric tension in the atmosphere takes place. The current still circulates upon the earth, but it gradually loses more and more of its energy, until the chemical rays of the sun make their power again felt before the dawning of the light, viz. about 2 a.m. in summer and 4 a.m. in winter.

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* "Student's Textbook of Electricity," p. 68.

I pass now to consider the magnetic influence which the moon exerts upon our earth. At one time it was disputed whether the moon had any magnetic influence at all upon the earth. Now if it could be shown that the moon, though similar in its physical constitution to the earth, was not in any way magnetically affected, this might certainly be urged as a difficulty in the way of admitting the sun to be the source of the earth's magnetism. But there is no longer any doubt existing upon this point. It remains, however, to be considered what is the character of the moon's magnetism, and in what way it acts upon the earth, since it is too powerful, we are told, to be looked upon as derived inductively from the earth, and yet acts differently to what we might expect if the moon were possessed of inherent magnetism.*

The magnetism of the moon is, there can be no doubt, like that of the earth, derived from the sun, although, for reasons which may be assigned, it differs to a certain extent in character from terrestrial magnetism. It is said, indeed, that the moon has no water and no atmosphere, and must be therefore different in some respects in its physical constitution from the earth. I cannot, however, but think that the earth would be in very much the same state and condition as the moon if we had in our neighbourhood a planet fifty times larger and eighty times heavier than our own, and if the time of the rotation of the earth upon its axis were lengthened out to a month. At present the ocean tide—which is, you know, an effect principally due to the attraction of the moon—rises in the open sea to the height of ten feet. But if the waters of the ocean were attracted by a body not eighty times lighter but eighty times heavier than the earth, and if all impediment to the full action of the attractive force of this body were taken away—the effect of the attractive force of the moon upon the waters of the earth is at present neutralised to a considerable extent by the centrifugal force which the rapid rotation of the earth communicates to them—we should in that case see the tide rise almost as many miles then as it rises feet now. A parallel force, then, being exerted upon the shallow seas with which the moon may be supposed to be covered, and the direct heat of the sun being poured down for a fortnight together without intermission upon the waters thus loosened in their hold upon the land, the consequence must surely be that, whatever water or ice may exist on the opposite side of the moon, there can be none on that which is turned towards the sun and the earth, which is the only side which falls under our observation.

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* "Rudimentary Magnetism," p. 294.

Now what has been said of the effect produced upon the waters of the moon by the earth's attraction and the influence of solar heat will apply with very much greater force to the effect which will be produced by the same causes upon the atmosphere of the moon. If the water becomes vaporised, the air, on the other hand, must become so extremely attenuated and rarefied that it can excite no surprise if no means we can employ are capable of detecting its presence. But if we have no reason for doubting that the elements of which the moon is composed are the same as those of which the earth and all the other planets are composed, in that case we have not any ground for doubting that the excited elements in the sun will act in the same way upon the corresponding elements existing in the moon as it does upon those existing in the earth, and will pervade both alike with the same magnetic influence.

The fact, however, that the moon rotates upon its axis only once in twenty-eight days, whilst the earth, which is fifty times larger, rotates once every twenty-four hours, gives a different character to the magnetism of the one and to that of the other. The earth has a positive and a negative current flowing upon its surface in opposite directions. The moon has negative electricity collected on one side, viz. that which faces the sun, and positive electricity on the other side, which is turned away from it. Hence arises the peculiarity of the influence which the magnetism of the moon exerts upon the magnetic current of the earth. I will endeavour to show how the effects produced by the moon's magnetism upon the earth may thus be explained.

We are told that the aspect of the lunar diurnal variation at Kew and Hobarton presents features of great simplicity as well as accord.* The form at both stations is a division of the twenty-four lunar hours into four equal or nearly equal portions, in which the magnet is attracted alternately to the east and to the west of its mean position, which is passed through four times in the progress of the magnet towards two extreme easterly and two extreme westerly deflections. This appears to be the general form of the lunar diurnal variation of the declination at all the stations at which it has been examined. It is also that of the corresponding variations of the dip and total force. In regard to all other points, the two stations which have been named are alike, but in regard to the direction in which the magnet is deflected (if, in conformity with general usage, we speak in both hemispheres of the north end of the magnet) the variation becomes west at Kew when it becomes east at Hobarton, and *vice versa;* the phases, while agreeing in hours at the two stations, having throughout opposite signs.

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* "Rudimentary Magnetism," p. 294.

As the moon in revolving round the earth never deviates more than five and a quarter degrees from the plane of the ecliptic, its pathway lies between these two stations. It is easy therefore to understand that, in whatever direction the terrestrial current is deflected by the moon's influence at one of these places, it will be deflected in the contrary direction at the other, the one place being to the north, the other to the south of the moon's course. We will take, therefore, one of these places, and endeavour to find out how the magnetic current is there affected by the influence which the moon exerts in the various positions which it assumes in relation to it, and we may thence infer generally how the magnetic current will be affected by the moon's influence in any other part of the earth.

Let me suppose, first, the illuminated side of the moon —that which is turned to the sun—to be shining upon the earth. Since the moon revolves so slowly that it may be almost looked upon as stationary, the electric character of that side of the moon will be negative. How then will the earth be affected by it? The atmosphere of the moon being stretched out an immense distance towards the central parts of the earth, and acting as a conductor to the moon's electricity, these parts, towards which the negative electricity of the moon converges, will be excited by a certain amount of statical electricity of an opposite kind to that of the moon. When the moon is on the meridian of Kew, Kew will be at that time nearest to the parts which are influenced by the moon's electricity, and will be then more than at any other time affected thereby. The magnetic current there will be drawn towards the south, and the needle will decline towards the west. Six hours later, when the earth has performed a quarter of its diurnal revolution, Kew will have reached the point most distant from the parts of the earth under the influence of the moon's electricity, and will therefore be little, or not at all, affected by it. The needle will consequently fall back again to the east. When another six hours have passed, and the earth has completed half a revolution upon its axis, Kew will be brought to that point which corresponds to the meridian which the moon is crossing on the other side of the earth. Now, you know, in the case of statical induction the body has its two sides excited with an opposite electric force. The effect therefore produced at Kew will be the same when it is immediately under the light of the moon and when it is on the other side of the earth exactly parallel to the moon. You may tell me that the electric state into which the central parts of the earth are thrown, which act upon the magnetic current at Kew, must be different in these two cases, being positive in the one and negative in the other. That is true. But however much these positive and negative electricities may differ in the chemical effects they give rise to on the earth, they do not differ in the attraction they exert upon the magnetic current, which consists in reality of two currents, the one positive, the other negative, flowing in opposite directions. Lastly, when the earth, after another six hours, has completed three-quarters of a revolution upon its axis, we have the same result as that which took place when the earth had completed but one-quarter of a revolution. Kew is removed again as far as it can be from the influence of those parts of the earth which are affected by the moon's electricity: the magnetic current resumes in consequence a more northerly direction, and the needle a more easterly declination.

The needle, in thus passing twice to an extreme westerly and an extreme easterly position, passes four times through what we may regard as its mean position. There is, however, a difference here I must notice. Whereas the extreme positions, both westerly and easterly, are reached in successive periods of equal portions of time, the mean position is not thus divided from them. The needle, *e.g.*, points to the mean position one hour or so before each of the westerly culminations takes place. It points again to it about three hours after each of these culminations has taken place. The reason of this is that the magnetic current, which flows from east to west, whilst the earth rotates from west to east, is drawn out of its course with so much greater force as it approaches nearer to the parts affected by the moon's electricity. Its deviation in the last hour is equal to that of the preceding five hours. But when once the current has been drawn out of its course it does not fall back into it immediately, the influence exerted upon it is relaxed gradually. It takes some time for the effects which that influence has produced to pass away.

We have considered how the moon acts upon the magnetic current when its illuminated side is turned towards the earth. A very few words will suffice to show that the action of the moon upon the magnetic current is similar when its dark side is turned towards the earth. The electrical character of this side of the moon will be positive; and this positive electricity being directed by the converging atmosphere of the moon towards the central parts of the earth will excite there negative electricity on the side of the earth turned towards the moon, positive electricity on the side turned the other way. But with whatever kind of electricity the equatorial parts of the earth are excited, the magnetic current, alike at Kew and at Hobarton, will, as we have seen, be drawn in that direction.

This positive electricity, transmitted to the earth by the moon when it is in conjunction with the sun, will continue to be transmitted by it so long as the atmosphere of the moon, which is always drawn out a great distance towards the earth, points in a direction away from the sun, *i.e.* from the time when the moon has entered into its last quarter to the time when it goes out of its first quarter, when there will be a change in the character of the electricity which it pours down on the earth. It may be noticed incidentally that M. Arago has observed a slight increase in the quantity of rain which falls to the earth during the second quarter of the moon. If this be só, it may possibly be due to the disturbed state of the atmosphere, which is the consequence of the electric change which takes place at this time. If the moon does produce any physical effects upon the earth, it is to the tropical regions, on which its action is principally concentrated, that we must look for the manifestation of her power. To this question I have nothing to say. My object has been to show that what we know of atmospheric electricity, as well as what we are told concerning the influence exerted by the moon's electricity upon the magnetic current of the earth, fully accords with the theoretical views I have put before you concerning the nature and the action of terrestrial magnetism.

LECTURE XV.

THE ROTATION OF THE EARTH UPON ITS AXIS.

The rotation of the earth upon its axis produced by the electric action of the sun.

A MAGNET made to revolve rapidly above a copper plate not in any way connected with it causes the plate to revolve along with it in the same plane. This revolution of the plate is, we are told, due to the action of the electric currents which are generated upon its surface by the moving magnet. The sun revolves in a vertical plane above the earth, and gives rise to electric currents upon its surface: we are going to examine whether the rotation of the earth in the same plane be not due to the action of these currents (Fig. 22).

There are in reality two currents, one positive, the other negative, flowing upon the earth's surface. I will speak first of the negative current. The negative electricity, which is generated upon the earth by the affinity which the negative elements upon its surface have to the excited positive elements upon the superficies of the sun, flows round the earth from west to east. As the earth's hemisphere rises on one side just as much as it falls on the other, the action of this current may be compared to that of a current flowing in a horizontal direction. The earth is an imperfect conductor, only a comparatively small portion of the negative electricity which is generated upon it is able to find a passage along its surface; the remainder discharges itself into the air, yet not before it has stirred the affinities which certain elements of the earth have to other elements in the sun, and has excited attraction between the one body and the other. We have then here two different currents or lines of force acting simultaneously upon the surface of the earth, the one in a horizontal, the other in a perpendicular direction. What will be the result? You will say, perhaps, that a body urged forward by two forces acting in different directions ought to move along an intermediate line, which will be the diagonal of a parallelogram, the sides of which represent the forces in action. That is true when the impetus first given to the body continues alone to act, without the intervention of any disturbing force. But in the case before us no sooner has the body under the influence of the perpendicular and horizontal currents begun to move along the diagonal of the parallelogram formed in the first instance than the relation existing between the forces in operation is changed, and each moment a new parallelogram is constructed and a new diagonal described. The revolution of the earth round the sun furnishes an illustration. The centrifugal motion communicated to the earth tends always to make it fly off at a tangent from its orbit, whilst the centripetal force of gravitation tends, on the contrary, to draw it in a perpendicular line towards the sun. The result is that the earth moves along the diagonal line of an ever-changing parallelogram, and travels round the sun, or rather round the centre of attraction which is common to the sun and its planets. You will say, perhaps, that the movement of the earth under the influence of its electric forces does not correspond with the movement of the earth under the influence of the centrifugal and centripetal forces. The earth does not travel along the diagonal of a parallelogram representing the horizontal and perpendicular lines of magnetic force of which I have spoken. It rotates upon its axis. It must be borne in mind, however, that as yet we have only considered the effect produced on the earth by the negative current, we have further to take into account the effect produced by the positive current, which will act in opposition to the negative current so far as the latter tends to draw the earth out of its orbit towards the sun, and will act in conjunction with it so far as it tends to communicate a rotatory motion to the earth.

The positive current flowing upon the earth comes to it from the sun. Now the first of the electro-dynamic laws tells us that successive portions of the same rectilinear current repel, or, as I should say, propel one another. Therefore the positive current, which proceeds from the sun, propels the earth, having a positive current flowing upon it away from the sun. But the earth being a very imperfect conductor, this positive current, like the negative current, is divided into two currents, the one flowing along the earth's surface from east to west, the other descending below its surface.* These two currents, which, as has already been explained in the case of the two corresponding negative currents, will flow in the direction of the two sides of an ever-shifting parallelogram, will be equivalent to one current flowing in the direction of its diagonal (Fig. 22). How will these two diagonal currents act? If the positive and negative currents of the earth be, as is generally supposed, equal to one another, they will cause the earth to turn round without approaching nearer to or receding farther from the sun. It is thus, we are told, that in the case of a primary and secondary spiral or coil—to which the sun and the earth may in some respects be compared as regards the action of the one upon the other—force has to be used to make the secondary approach to, or to make it withdraw from, the primary, in order in the first instance to overcome a repulsion, in the latter to overcome an attraction which is aroused.† If, on the other hand, we should suppose the positive and negative currents to be unequal in power, what would follow? It is evident that the effects produced upon the earth by electric attraction cannot for a moment be compared to the effect produced upon it by the forces of gravitation and inertia. Electricity acts upon the external particles of the earth's surface. Gravitation and inertia act upon every particle which the mass of the earth contains. How infinitesimally small then must be that residue of force to which the difference between the two perpendicular currents acting upon the surface of the earth will amount, when compared to the whole combined force of gravity and inertia, each of them exerting its influence upon the entire mass of the globe! But let that residue be what it may, the effect of it would be, not to draw the earth in a direct line nearer to the sun, but to increase in some small degree the ellipticity of its orbit, for the earth's orbit is, as you are aware, elliptical. This is said to be owing to the attraction which the moon and the other planets of the solar system exert upon the earth whilst it accomplishes its circuit round the sun. It may also be connected with the onward march which the sun makes through the regions of space, carrying along with it its revolving planets. If then we should suppose an inequality to exist between the electric forces acting upon the motion of the earth, the only consequence of this would be that we should in that case have to add another to the causes already named contributing, each one in its own degree, to modify the elliptical character of the earth's orbit.

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* I take no notice here of that portion of the positive current which is taken up by the revolving atmosphere. Its action, so far as it is felt upon the earth, will not differ from that of the current flowing upon its surface. But if there be any electricity passing from the sun by means of the earth to a more distant body, that would form part of the current here spoken of as tending to propel the earth from the sun.

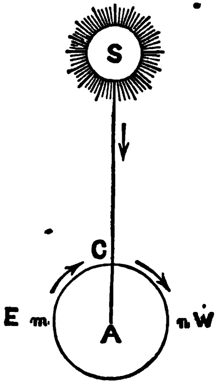
† "Notes on Electrical Phenomena," by Prof. Tyndall, note 287.

I have gone thus fully into these explanations because, in my opinion, they serve to show how the rotation of the earth upon its axis naturally follows from the double action exerted by the positive and negative electric currents upon the earth. I proceed next to another kind of proof. Setting aside the distinction between the positive and negative currents, we will make to the case before us the application of the electrodynamic laws which relate to the action of currents one upon another, and see what the result must be.

I may be told that these laws have reference to the action of primary currents, whereas I have represented the magnetic current upon the earth as called into existence by the inductive power of the sun. It cannot, however, be doubted that when one body has been not simply thrown into an electric state but magnetised by another body, both of them will from that time act upon each other, to some extent at least, as primaries. It is in this relation then that the sun and the earth stand towards each other, and the mutual action of their currents one upon another will therefore be governed by the following law: *Currents whose directions are inclined to each other at any angle attract each other, when they both flow towards the vertex of the angle, or when they both flow from it, and repel each other when one of them flows towards the angle and the other flows from it.*

In coming now to the application of this rule, it has to be borne in mind that by the direction of the current we mean the direction in which the positive current flows. There is, *e.g.*, a twofold current, one positive, the other negative, between the sun and the earth. But the direction of the positive current is from the sun to the earth. There is in like manner a twofold magnetic current flowing round the earth, but the direction of the positive current is from east to west. How then will these currents act one upon the other? The explanation which Ampère has given of one of the experiments whereby he succeeded in causing a magnet to rotate upon its axis will help me in setting this matter in a clear light before you. Having floated a magnet in an upright position in a vessel filled with mercury, and having in the uppermost part of the magnet, which stood above the liquid in the vessel, formed a cavity, he filled it with mercury, and then introduced into it one of the terminals of an electric battery, whilst he connected the other with the outer edge of the mercury in the vessel. In this way, by causing the electric current which he communicated to the magnet to pass off from it horizontally, he effected the rotation of the magnet (Fig. 18). It will be more convenient for us to reverse the direction in which he made the electric currents flow in his experiment. The consequence will be that the magnet will rotate in the same way in which the earth rotates, and will furnish us with a most apt illustration of the manner in which the earth's rotation is effected. A few words will suffice to explain the annexed figure, and enable you to understand the action which takes place between the currents of the sun and of the earth.

SCA represents the electric current, which, falling perpendicularly upon the earth, descends below its surafce; *m*C*n* represents the magnetic current of the earth, flowing from east to west. Between *m*C and CA there will be repulsion, because *m*C is flowing towards the angle C, and CA is flowing from it. Between CA and C*n* there will be attraction, because both are flowing from the same angular point, C. It is manifest, however, that the repulsion of *m*C from CA, and the attraction of *n*C to CA are not conflicting forces. They both act in the same direction, and will bring about one common result. Under their influence the earth will, like the magnet, be made to rotate in that direction, *n*C*m*, in which the negative magnetic current flows; and since all the rays of the sun which descend upon the earth may, on account of the immense distance of the sun from the earth, be looked upon as parallel to those which fall upon its centre, it follows that the action of all must be in this respect alike, and that the effect produced by them will be the same in character though not the same in degree.



But there is no proof, it may be said, that there is such an electric current as CA descending perpendicularly below the surface of the earth. That the greater part of the electricity poured down by the sun upon the earth is immediately absorbed beneath its surface cannot be for a moment doubted. Now, just as the line *mCn* represents the horizontal propelling force which is exerted by the magnetic current at C, as well as at every other point upon the earth's surface, so the line CA represents the perpendicular propelling force which is exerted by the sun's electric current at the point C, as well as at every other point upon the side of the earth which the sun shines upon; and these two forces acting simultaneously everywhere upon the earth must, in accordance with the electro-dynamic laws, have the effect of producing the earth's rotation.

In giving you this account of the manner in which the earth, being free to move and having an electric current circulating upon it, must be affected by a perpendicular current falling upon it, I have, as I have already told you, done no more than put before you Ampère's own explanation of the experiment whereby he effected the rotation of a magnet upon its axis. Having, then, before our eyes the proof that a magnet may be made to rotate by having a perpendicular current transmitted to its surface, I do not see how we can admit that the earth has a magnetic current circulating about it, and has also a perpendicular current falling upon it, and yet refuse to see between the action of these currents one upon another and the earth's rotation any connection. To me it seems that

Ampère employed, without being conscious of it, the very same means to produce the rotation of the magnet which produce the rotation of the earth.

Let me point out what may be found for some a simpler way of looking at this argument. Two neighbouring conductors of electricity will act one upon another, and, if one of them is free to move, that one will alter its position in some degree. We have an example of this in the movement of a magnetic needle when brought near to a conducting wire. SCA and *mCn* are two such currents brought into close proximity. The magnetic current *mCn*, which flows upon the earth's surface from east to west, is not free to change its course, which is determined by the direction in which the sun rotates. SCA, the current of the electric rays of the sun, travels in a straight line to the surface of the earth, but, if upon reaching the surface of the earth it falls under the influence of any other current, it will be liable to be deflected from its course. CA comes under the influence of *mCn* at the point C, and turns in the direction of that current. This attraction of CA to C*n*, which is exerted not only at the point C, but everywhere on the surface of the earth upon which the sun shines, is the cause why the earth rotates upon its axis from west to east.

LECTURE XVI.

OBJECTIONS ANSWERED.

The inapplicability of the electro-dynamic laws to the case before us—The insufficiency of the force of the magnetic current to produce the rotation of the earth—The great velocity of the rotation of the earth in relation to that of the sun—The regularity of the rotation of the earth in compaison with the variableness of the electric action of the sun—The absence of similar effects produced upon the moon.

I PROCEED to reply briefly to the objections which may be urged against the conclusion arrived at in the preceding lecture. I have, it may be said, taken my stand upon the electro-dynamic laws, as proving that the rotation of the earth must be admitted as a consequence proceeding from the electric action of the sun. But can these laws relating to the mutual action of the currents upon magnets and conductors be brought forward as in any way applicable to the present case? Can the sun and the earth be said to come under the description of neighbouring conductors? Well, they are certainly not very close neighbours. But if it be admitted, as it must be, that the earth is not placed outside the sphere of the sun's electric influence, they must be included together under this category; and, this being so, the laws of electro-dynamics must have their application in this case just as much as in any other.

But granting, it may be said, that a mutual electric action does exist between the sun and the earth, inasmuch as both bodies are in an electrical state and are at the same time in motion; yet is not the cause assigned manifestly insufficient to account for the effect which is produced? Is it conceivable that those weak currents, which elude the observation of the senses, and whose presence is only made known to us by the magnetic needle, should be equal to the task of turning round upon its axis a vast and ponderous globe, some millions of millions of tons in weight? In judging of the force belonging to terrestrial magnetism and to the sun's electrical influence upon the earth, it must be borne in mind that, insignificantly small though they may be at each individual point of the earth's surface, they are ever in action in every part of the earth on which the sun shines; that is, at all times over more than one-half of the globe. I do not know how much force would be required to make the earth rotate upon its axis, but I may ask, what reason is there for supposing the amount of force required to be so very great? I have seen how easily a pole, floating in the water, upon which some unwary youths had ventured, was turned round, capsising the little urchins into the stream. Now the globe of the earth, however vast its weight, hangs in equilibrium, not being drawn to one side more than to the other, whilst the medium in which it is suspended offers indefinitely less resistance to the motion of a body than either water or air. The magnitude of the earth tells as an argument the other way. A globe of vast size is turned round with almost as much facility as one of smaller dimensions in an unresisting medium, whilst the larger the surface presented to the action of the solar rays—each ray of light contributing its own little quota of electric force—the greater the moving power called into play. Hence we find the planets rotate, each one at a greater velocity in proportion to its size. Jupiter, which is a hundred times larger than the earth, rotates upon its axis in less than ten hours. Saturn, the next in magnitude, revolves in twelve hours. Mars, which is much smaller than the earth, and Venus, which is nearly the same size as the earth, revolve in about the same time. I do not pretend to say that there may not be other circumstances, besides the extent of the area presented by bodies to the action of the sun, which affect the rate at which they will revolve upon their axis. But this at all events is plain, you cannot upon the ground of the magnitude of the planetary bodies refuse to admit that the electric currents which the sun generates upon them may be the cause of their rotation.

Again, it may be urged that when one current gives rise to another the induced current is of inferior strength and velocity to the inducing current. If then the earth's rotation were caused by the motion of the electric currents which have their origin in the sun, which is an electrified body in motion, we should expect to find the rotation of the earth less rapid than that of the sun, whereas the earth rotates in twenty-four hours, the sun in twenty-four or twenty-five days.

I may observe it is not always the case that induced currents possess less strength than the primaries which excite them. We are told that induced currents in a Ruhmkorff's coil may possess thousands of times the electro-motive force of their primaries; the number of convolutions in the secondary coil, far exceeding in this case the number in the primary coil, gives rise to this increase of strength. But to return to the objection. The sun is supposed to complete a revolution upon its axis in twenty-four or twenty-five days, because the spots seen near the equator of the sun make an entire circuit in that space of time. We do not know, however, that there may not be an electric current revolving round the sun with still greater velocity. But not to insist on any other point, it is sufficient to say that the sun's rotation is a movement incomparably more rapid than the earth's rotation. The sun is 1,400,000 times greater in bulk than the earth; and yet it takes only twenty-five times the period which the earth takes to complete a revolution upon its axis; in other words, it revolves with a rapidity 55,000 times greater than that of the earth. Now I do not deny that we should expect to find a vast difference in the rate of the movement of a primary and of that of a secondary placed so widely apart, but is not the difference here large enough to satisfy all demands?

Once more, it may be said the electric power which the sun exerts upon the earth is not uniformly the same. When it has a prevalence of spots upon its surface, it displays an exceptional degree of energy. Hence the rotation of the earth, if it depended upon the electric action of the sun, would be irregular in its movement, whereas we know that for many ages the length not only of the year but of the day has been absolutely invariable.

The surface of the earth over which the electric forces are distributed being very large, and the direct action of the sun being limited to one-half of the earth, it is easy to understand how a certain degree of variableness in the action of magnetism should be found to exist at different places and at different times, without producing any sensible effect upon the regularity of the motion of the earth—just as a fly-wheel being attached to machinery in motion serves to equalise the irregularities arising from any temporary disturbing cause, and to produce a resultant of constant force. Now we have no evidence of there being anything more than partial changes in the magnetic current which flows upon the earth. We are told, as has been already stated, that the intensity of the current is at present decreasing in Europe; it is in the same proportion increasing in Asia. It is quite true that at times the sun displays a greater amount of electric energy, but this excess of energy expends itself for the most part in the atmospheric disturbances to which it gives rise. The earth, which is a bad conductor, transmits always the same or about the same quantity of electricity, viz. as much as can find a passage along its surface; the remainder it absorbs beneath its surface or discharges into the air. If any greater impetus is given to the flow of magnetism upon the earth, the same cause which produces this effect upon the earth will produce a similar effect upon the electric condition of the moon. Thus the increase in the one will be met by a counteracting increase in the other. For the electric currents excited upon the surface of the moon will flow in the direction opposite to those on the earth. This will be made clearer by what has to be said in reply to the next objection.

Lastly, it may be urged that if the electric action of the sun caused the rotation of the earth, it would have the same power to cause the rotation of the moon; whereas the moon, which takes twenty-eight days to revolve round the earth, takes the same time to rotate upon its axis, having always the same face turned towards the earth. The revolution which the moon makes round the earth, whilst the two together revolve round the sun, is, as you know, the consequence of the attraction of gravitation which the earth exerts upon the moon. It seems probable that it is the opposition which there is between the electric currents of the earth and those of the moon which more than anything else retards the moon's rotation, and so causes it to present always the same face to the earth.

We should have expected the moon to rotate, under the electric influence of the sun, much more slowly than the earth; for, in the first place, the moon is only the fiftieth part of the size of the earth, and the smaller the area presented by a body to the action of the sun the less will be the electric force generated upon its surface. Again, the earth mainly owes its conducting power, imperfect though it be, to the fact that nearly three parts of its surface are covered with water, whilst the other part is to a certain extent suffused with moisture; whereas it is pretty certain that no water exists upon the surface of the moon, or none, at all events, upon that side of the moon which is exposed to the rays of the sun, *i.e.* upon the only side of the moon upon which the sun's electric power is exerted. It follows that the moon cannot be compared to the earth, either in point of electric energy and force, or in point of electric conductivity. But not only are the currents which flow over the surface of the moon weak in themselves, they are stayed in their progress by the opposition which they meet with from the currents flowing in the opposite direction round the earth. For it is evident that the currents flowing upon the side of the earth which is turned towards the sun and those flowing upon the side of the moon which is turned towards the sun, must have the same direction; and it follows, therefore, that when the earth is between the sun and the moon, and in like manner when the moon is between the sun and the earth, the currents flowing upon the contiguous sides of the earth and of the moon must flow in opposite directions to one another. It is true the electricity of the moon exercises but little influence upon the more powerful magnetism of the earth. The principal reason for this is because the moon does not rotate in regard to the earth. There can be no doubt, however, that the magnetism of the earth, which is not only in itself more powerful, but which does rotate in regard to the moon, exercises a very great influence upon its electric condition. And, in addition to this, it has to be borne in mind that the atmosphere of the moon, stretching out a great distance towards the centre of the earth, and, attracted by the force of gravitation both to the one body and to the other, must also have some effect in hindering the moon from rotating upon its axis more quickly than it revolves about the earth.

These reasons are perhaps sufficient to explain why it is that the earth and the moon do not rotate with the same velocity under the electric action of the sun, and also why the moon shows always the same face to the earth, and in its action upon the earth appears to be endowed with the properties, not of current, but of statical electricity. I do not know any other objections which require to be answered, and so I draw this lecture to a close.

LECTURE XVII.

CONCLUDING REMARKS.

Magnetism considered in its relation to other sciences—In relation to matters of practical utility—In the bearing which the conclusions drawn from it have upon certain theological questions, viz. the Mosaic account of the Creation, the Galileo controversy.

THE subject upon which I have been lecturing is one of a purely scientific character, and, whilst treating it in a very simple and elementary way, I have endeavoured to put it before you in that light. It may be doubted whether there is any science properly so called which stands by itself alone, without having any connection with other sciences, or any bearing upon the practical uses of man's life upon the earth. At all events it is quite certain that this is not the case with magnetism. Electricity and magnetism are not merely connected together, they are one and the same principle acting in substances which are differently constituted. And, as I have already endeavoured to show, chemical and electrical agencies are identical in their nature, and differ only in degree and in the circumstances under which they act, and, to the same extent, in the results which they produce. There are, however, other sciences with which magnetism may be considered to have points of contact. It may be hoped that the discovery, when made, of the physical cause of the rotation of the earth will lead on to the discovery of the physical cause of the rotation of the sun upon its axis, and so make us more fully acquainted with the physical causes of the revolution of the earth and the other planets round their common centre of attraction. Thus our progress in this science would be a prelude to a further development of the science of astronomy.

Again, we may be certain that our increased knowledge of the science of electricity and magnetism will not be barren of practical results, but will be directly applicable to many useful purposes. Navigation, *e.g.*, will be greatly benefited if we once discover the cause of the magnetic currents which flow round the earth, and the laws which regulate their movement, together with the periodic changes to which they are subject. In like manner, we may, by becoming better acquainted with the nature of electricity, learn to make a more skilful use of the powers which it places at our disposal, and to obtain, *e.g.*, the advantages so long expected from the discovery of the electric light. But I pass from the consideration of these more obvious results which may be anticipated from any advance which is made in the science of magnetism and electricity to touch upon one or two points less likely to attract attention.

One argument brought against the Mosaic account of the Creation is founded upon the alleged impossibility of light existing upon the earth, as is there represented, before the sun and moon had been set in the firmament to shine upon the earth. It is sufficient, however, to say we have the aurora borealis and australis shining constantly upon parts of the earth, and we have a phosphorescent light illuminating parts of the planet Venus which are hidden from the rays of the sun; in other words, the affinities which different particles of matter have one to another are found capable, under certain circumstances, of developing an electric light, and it is certain these affinities which exist now between different particles of matter must have existed from the very beginning.

Another argument brought against the inspiration of the Book of Genesis rests upon the supposed impossibility of reconciling the six days of creation with the proofs which geologists set before us of the great antiquity of the world. Sacred Scripture calls the light day, and the darkness night; and, speaking of the days of the earth before it was yet illuminated by the rays of the sun, it says that they were made up of evening and morning, that is of a succession of two periods—the length of which it does not in any way determine—the one characterised by light, the other by darkness. If any one chooses to interpret these days as being days of twenty-four hours he may be free to do so, but he must understand that this is nothing more than a private opinion of his own upon a question upon which the sacred writer has said nothing one way or the other. Most persons, however, will be disposed to adopt a different interpretation. We are taught both by nature and by revelation, and upon a point upon which revelation is silent and nature speaks we do well to listen to the voice of nature and follow her teaching. The sacred writer tells us that, when as yet no sun shone upon the earth, evening and morning taken together, *i.e.* a period of darkness and a period of light succeeding one another upon the earth, made up what he calls a day; and not being commissioned to instruct us in the natural sciences, he says nothing more upon the subject, but proceeds to narrate what were the works accomplished by God in each successive period.

If any one should say that the mere fact of a period of darkness being followed by a period of light is not enough to warrant the use on the part of the sacred penman of the word day, we ask, what is it then constitutes a day? Not a particular number of hours of light, followed by a corresponding number of hours of darkness, because the proportion between the number of the hours of light and darkness varies according to the season of the year. Not simply the space of twenty-four hours, because we speak of the day in the planet of Jupiter being a day of no more than ten hours' length, and of a lunar day being lengthened out to twenty-eight of our days. Moreover, if we should begin, say at nine o'clock in the morning, and count twenty-four hours, we should not call that one day, but a part of two days. What we mean then by a day is one orderly succession of light and darkness, brought about by that which is the natural cause of the succession of the one after the other, viz. the rotation of the earth upon its axis. Now if we apply the word day in this signification to our present case, what will be the result?

If the rotation of the earth be produced by the sun's electric action exerted upon it, we are at a loss to say how long a time may have passed away before the earth accomplished its first rotation upon its axis, when as yet the sun had not begun to exert its electric power and to shed its influence upon the earth, bringing forth order and regularity of motion out of the strife of the conflicting elements of which it was composed. If there were any electric force, however small, exerted by the sun upon the earth, it may be presumed that whatever changes upon the face of the earth might take place, a rotation upon its axis would in course of time be accomplished, and when one rotation had been accomplished, we should expect that the next would take place in a shorter space of time, because, when an impulse of this kind had been once given to the earth, however weak it might be in the first instance, it would naturally continue to operate and continue to gain new force until it was at length fully developed.

If, on the other hand, we should suppose the sun to exert no electric influence whatever upon the earth, we might still presume, I think, that the unsteady action of the different forces battling upon the earth—a vast globe hung in space revolving round its centre of attraction—must eventually turn it round upon its axis, however long it might take to do so. It would not, however, be until those scattered forces were marshalled in order and made to act in support of one another that the mighty mass of the earth would have to give way before them; in other words, it would not be until the face of the sun was unveiled, and its light was poured down upon the world, and the magnetic current began everywhere to flow in the same direction, that the rotation of the earth would be performed with ease and with regularity, with precision and speed, although we may be permitted to suppose that even then the rate at which the earth rotated upon its axis was not so great as that to which it ultimately attained.

You will perhaps ask what is the inference I would have you draw from what has been said. It is this: if there is any one who denies that the sacred penman can with propriety have used the word day to denote a period of darkness followed by a period of light without implying the existence of some cause determining the relative length of these two successive periods —a cause which must at the same time establish a connection between the days that preceded and the days that followed after the shining of the sun upon the earth—as it is plain that ever since that time no other natural cause of the division between one day and another can be pointed to but the rotation of the earth upon its axis, let him take that same cause of division between one day and another, and apply it to the time before the sun shone upon the earth. It will be seen at once what little ground there is to affirm that any contradiction exists between the conclusions of science and the teaching of sacred Scripture on this subject.

The next point to which I am going to refer brings before us again the question how we are to harmonise together the teaching of science and the language of sacred Scripture. Galileo taught, as is well known, that the earth rotated upon its axis at the same time that it revolved round the sun. Copernicus, a Polish priest, had without let or hindrance taught the same before him. But Galileo did not stop there. He wanted to have the sacred Scriptures interpreted in accordance with his theory. If the inspired writer tells us that at the voice of man the sun stood still and the moon stayed until the people had avenged themselves upon their enemies, he contended that this miracle of the prolongation of the day must be considered as recorded in that manner in which it was believed to be accomplished, viz. by the standing still of the sun, not in that manner in which it was actually wrought, viz. by the standing still of the earth.

Now it being admitted, as I have already said, that the sacred Scripture has not been written to teach us natural science, and it being admitted also that truth cannot be opposed to truth, it must be lawful to depart from the literal sense of the words of Scripture, not only whenever we may gather from the context itself or from any other part of Scripture that they are meant to bear a figurative or allegorical meaning, but whenever a literal interpretation would require us to yield assent to anything which we know to be false. Could that be said to be the case here? Had Galileo established the truth of the Copernican theory when, with no little danger of unsettling minds, he pressed forward his views for bringing the interpretation of Scripture into accord with the discoveries of science? It is admitted that he had not succeeded in doing so, and he was expressly told that there would be time enough to consider how the language of Scripture was to be interpreted so as to accord with the Copernican system when the Copernican system was proved to be true.

But though it be admitted that Galileo was not in the right when we simply regard this question, thus prematurely raised, in a moral point of view—it would be out of place for me here to dwell upon the moral aspects of this case—must we not own him to have been in the right when we are considering this question from a scientific point of view? What I mean is this: the truth of the Copernican system is now accepted by all; do we not agree with Galileo in departing from the literal sense of the words of sacred Scripture when it tells us that at the word of Josue the sun and the moon stood still? I do not quarrel with those who answer in the affirmative. Arguments are not wanting in support of their opinion. For myself, however, holding that the rotation of the earth upon its axis is an effect produced by the rotation of the sun, I think the contrary opinion more consistent both with Scripture and with science. No doubt, if it so pleased the Almighty, He might have made the earth of itself stand still, and in this manner have prolonged the light of the day. It is true that in this case the sun continuing to revolve would urge the earth to rotate the same as before; but by the divine power it could be kept motionless. It is true, in like manner, that the natural effect of such a sudden and instantaneous stopping of the earth in its rapid rotation would be to overturn and dash to the ground everything that was standing upon the face of the earth; but the same act of omnipotent power, which so suddenly arrested the motion of the earth could extend itself to the prevention of whatever fatal consequences would naturally follow therefrom. It is true, once more, that the miracle explained according to this view might appear, so far as it relates to the moon, to be in some sense a superfluous act of divine power, inasmuch as the sun being over Gabaon, and the moon over the not far distant valley of Ajalon, the moon must have been almost directly between the sun and the earth, and must have had therefore its dark side turned upon the earth. Still I admit that all that is recorded in the sacred Scripture may have happened in this way, because with God nothing is impossible. But is there any proof that it happened in this way? If there is none, I cannot but think it far more simple and natural if we suppose these things were brought about in the order and in the manner in which the sacred Scripture represents them as taking place; if, in a word, we suppose the sun and the moon were made to stand still. The rotation of the sun being the cause of the rotation of the earth, if the sun stood still we should have the same effect brought about less abruptly, more gradually in regard to the earth. As soon as the sun ceased to revolve, the magnetic current would at once cease to flow upon the earth, and the affinitive powers, which had been exerted by the sun before in such way as to make the earth rotate, would be exerted now in such way as to arrest the earth's rotation. The momentum which the earth had already acquired would not of course cease all at once. It would carry the earth on, and all that was upon the face of the earth, with a continual slackening of speed, so that no new miracle would be needed to rectify the consequences that naturally would follow from any abrupt stoppage of the earth's rotation. Over and above the action exerted by the sun upon the earth in staying its progress, there would be likewise a similar action exerted by the moon. For it is not to detract from the miraculous character of the event to point out that the sun, and the moon also, having its dark side turned towards the earth, would be endowed with positive electricity; whilst, on the other hand, the side of the earth which was turned towards the sun and the moon would, from the time the magnetic current ceased to flow upon the earth, be made more powerfully negative than it was before. If the movement of the sun and moon are the natural causes of the rotation of the earth, why then may we not believe that God arrested the movement of those heavenly bodies, and so stayed the rotation of the earth? For, observe, both of the views which I am contrasting together agree in holding that the rotation of the earth was for a time suspended. They differ only in this respect, that the one regards it as a consequence of the sun and moon being made to stand still, whilst the other regards it as an immediate effect of the divine operation. Now if we believe, upon the authority of sacred Scripture, a miracle to have been wrought on this occasion, it is surely more consistent to hold that this miracle was wrought in the way in which the sacred Scripture records it to have taken place, when no sufficient reason can be alleged to the contrary.

I have said enough upon this point, having gone perhaps further into details than may seem to be consistent with my professing to do nothing more than touch upon a subject coming incidentally before me, and yet not further, I think, than was necessary to make good my assertion that it is free for us to hold that, in answer to the prayer of Josue, the sun and moon were literally made to stand still in the heavens, so as to allow time for the Israelites to complete the victory which God had granted them over their enemies. "So the sun stood still in the midst of heaven, and hasted not to go down the space of one day. There was not before nor after so long a day, the Lord obeying the voice of a man, and fighting for Israel."

NOTE TO PAGE 65.—When either a zinc plate or a copper plate is put alone into an insulated vessel of water its external surface shows negative electricity. The oxygen element of the water, having an affinity for both metals, although for copper in a less degree than for zinc, and being also negative in relation to both of them, will produce negative electricity upon the outer extreme part of each. It is, however, commonly held (Ferguson's "Electricity," p. 110) that when the two plates are put together into the insulated vessel of water, there is, before contact takes place, the presence of negative electricity made manifest at the end of the zinc plate, and the presence of positive electricity at the end of the copper plate. I have considered that the presence of positive electricity at the outer end of the copper is to be explained by the action of the zinc plate upon the copper plate through the conducting medium of the water. There seems, however, reason for believing (Professor Jenkin's "Electricity and Magnetism," p. 44) that, up to the time of actual contact, the copper plate continues to show at its extremity signs of negative electricity. Perhaps both opinions have a certain foundation of truth. The action of the two metals before they are excited cannot reach to any distance. When the plates are put very near to each other, the zinc may exert an influence upon the copper and throw it into a state of positive electricity. When they are not close to one another, they may have no effect upon one another. In that case they would, up to the time of contact, be affected only by the oxygen in the water, and would both show negative electricity at their outer ends.

NOTE TO PAGE 105.—There are other causes besides those which I have named which directly interfere with the propagation of the sound of a peal of thunder.

Professor Tyndall has made known to us that the interposition of heterogeneous strata of air obstructs the transmission of sound. As clouds intercept the light coming from the sun, so these aerial fogs, when they cross the path along which sound is travelling, deaden its force, if they do not even sometimes extinguish it altogether. The causes which I have dwelt upon are those which have to do, not so much with the propagation of the loud report produced by thunder, as with its first rise and outburst.

NOTE TO PAGE 319.—It would be a more difficult task to effect the rotation of a magnet by causing a charged body or an electric conductor to revolve vertically over it in its immediate neighbourhood, than to effect its rotation in the manner in which Ampère did, viz. by causing the direct current of a galvanic battery to act upon the circulating current of the magnet itself, because the amount of electricity developed by the electric machine is incomparably less than that generated by the galvanic trough. But, should the experiment ever be successfully performed, it would be accepted as a more perfect illustration of the earth rotating under the electric influence of the sun.

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